11-21-2013

Lessons Learned from the First Year Implementation of a Two-Track, Reformed Introductory Biology Course

Dina L. Newman
Rochester Institute of Technology

Gary R. Skuse
Rochester Institute of Technology

Dawn Carter
Rochester Institute of Technology

F. Harvey Pough
Rochester Institute of Technology

Leslie Kate Wright
Rochester Institute of Technology

Recommended Citation

Newman DL, Skuse GR, Carter D, Pough FH, Wright LK (2013) Lessons Learned from the First Year Implementation of a Two-Track, Reformed Introductory Biology Course. 2013 NABT Biology Education Research Symposium Proceedings. https://nabt.org/files/galleries/Lessons_Learned_from_a_2-Track_Intro_Course.pdf

LESSONS LEARNED FROM THE FIRST YEAR IMPLEMENTATION OF A TWO-TRACK, REFORMED INTRODUCTORY BIOLOGY COURSE

Dina L. Newman, Gary R. Skuse, Dawn Carter, F. Harvey Pough, and L. Kate Wright
Gosnell School of Life Sciences, Rochester Institute of Technology, Rochester, NY

Abstract

The design, implementation and assessment of a novel, two-track, reformed introductory biology sequence are described in this paper. Course reform was based on the recommendations by the 2009 *Vision & Change* report from AAAS. Both tracks were based on guided inquiry, with an emphasis on constructivist pedagogy. One track included only students entering college with Advanced Placement Biology credit (N=24), who were given a studio style course that focused on the investigation of the phenomenon of "vanishing amphibians," from molecules to ecosystems, over the entire year. The other track included the remaining students (N=68), who received more direct content instruction but through the use of numerous student-centered, active learning methods. The "AP Scholars" section entered with higher and more consistent levels of prior knowledge, but both sections made identical normalized learning gains and expressed satisfaction with the course, particularly the reformed aspects. The "AP Scholars" identified strongly as scientists and enjoyed the investigative nature of the course. The two-track course is now in its second year, and changes are being made in accordance with the lessons learned from the first year. This two-track system could serve as a model for other institutions looking to change their introductory biology sequence.

Subject/Problem

Vision and Change, a report on the state of biology education in the United States (AAAS, 2009), called for major changes in the way that biology is taught at the undergraduate level, including more active learning strategies and moving from a content-based to a concept-based pedagogy. We have used this "Call to Action" to inform the redesign of an Introductory Biology sequence for majors at a large, private, highly undergraduate university. Previous work strongly supports the student-centered, conceptually driven method of instruction. Students enrolled in redesigned courses in various formats at numerous universities have performed better than their peers in traditional courses, and the new courses have been particularly successful at engaging students and improving overall satisfaction (Armbruster et al., 2009; Campbell et al., 2011; McDaniel et al., 2007; Ueckert et al., 2011).

We designed a novel, two-track system, based on the incoming preparation of students: those who entered the university with AP credit in biology (score of 3 or higher on the AP exam) were placed in one section, hereafter called AP Scholars (APS), while the remainder were enrolled in a reformed version of the traditional sequence, hereafter called Reformed Classroom and Lab (RCL). This division allowed us to tailor instruction in each section to the populations' different levels of prior knowledge and motivate the APS students by giving them a unique freshman experience. The APS section consisted of 24 students, who met twice a week for three hours at a time in a studio-style laboratory. The RCL section contained 68 students, who were split into two sections for twice weekly 80-minute sessions of classroom activities and three sections for a separate weekly three-hour laboratory. All three of these settings (APS studio, RCL "lecture" and RCL lab) were led by different instructors.

Gender, underrepresented minority (URM, defined as African American, Hispanic/Latino and Pacific Islander) and English Language Learner (ELL) rates were calculated for each section (Table 1). The ELL groups included several Deaf students whose primary language is American Sign Language (ASL). The percentage of female students was slightly higher in the APS section while the percentages of ELL students and URM students were higher in the RCL section. Socio-economic data was not available to us.

Table 1. Demographics of the two sections.

	RCL (n = 68)	APS (n = 24)
Female	50.7%	60.9%
English Language Learners	14.5%	4.4%
Underrepresented Minority students	11.6%	4.4%

Both course designs used guided inquiry as the primary conceptual framework, but differed in several significant ways. APS was primarily a student-driven course; the activities did not follow a particular order of topics, nor did it rely on the textbook for discussion material. Discussions and activities were based on the topics encountered during the progression of the investigative laboratory projects. DNA replication might be a discussion topic, for example, if the students were designing a PCR-based assay in the lab. Textbook material was not delivered to the students but was intended as reference or review material. To ensure mastery of the content, though, students in both the APS and RCL sections completed the same weekly online quizzes based on textbook readings (Hillis, 2012).

The APS course allowed students freedom to explore and investigate a high-profile biological phenomenon throughout the year in order to place their prior knowledge into a context that would allow them to develop deeper understanding of all the core concepts, while simultaneously developing the core competencies outlined in *Vision and Change*. The yearlong theme was "vanishing amphibians", which refers to the current extraordinarily high rate of extinction of frogs and salamanders throughout the world. The phenomenon is among the hottest topics in biology, with 541 publications appearing between June 2012 and May 2013 (http://amphibiaweb.org/declines/lit/index.html). This theme was chosen as a way of emphasizing the dynamic nature of science and the continuity of biological processes across all levels of organization, from molecules to ecosystems. For example, the pathogenic fungus *Batrachochytrium dendrobatidis* (Bd) has been linked with the worldwide decline of amphibians (Fisher et al., 2009; Kilpatrick et al., 2010) This phenomenon can be studied at the level of microbe-host interactions (e.g. *How does the secretion of Bd-proteases affect the normal flora of infected frogs?*), all the way up through the level of global-climate change (e.g. *Is there a connection between Bd infection range and increasing global temperatures?*). Students read and discussed the literature, and designed and conducted experiments to investigate the phenomenon using amphibians they collected locally. In order to take full advantage of laboratory time, a fair amount of online activity was required of the APS section. Students participated in a Facebook group (initially they were required to post, while later in the course it was used as extra credit); discussed papers in an online format using *Nota Bene* (NB), a collaborative reading and annotation tool (Wright et al., 2013), participated in Adobe conference chats; wrote research blogs to help them see the big picture of what they were doing in lab; and contributed to wikis in order to develop a manual of laboratory methods.

RCL was taught using numerous active learning strategies in the classroom, including clicker questions, group problem solving, modeling, case studies, and worksheets based on constructivist theory. Unlike the APS section, these lessons were specifically directed toward the material described in the assigned textbook chapters and the order of topics generally followed that of the textbook. In the laboratory, these students worked on 4 to 5-week investigative projects that included hypothesis testing, analysis of data and an emphasis on scientific communication skills. In one project, for example, students investigated amylase enzymes isolated from various sources (human, plant and bacteria) at all levels of information, from the gene (DNA) to functional protein product. This project allowed students to explore structure-function relationships, compare homologous genes from different organisms and think about evolution. The year-long laboratory portion culminated in student-designed independent research projects.

Research Design

We hypothesized that students in both sections would show significant learning gains in core concepts and core competencies, and that the APS students would not fall behind their RCL peers due to the lack of directed instruction on the textbook topics. Since the APS students used the research literature as their primary source of information and conducted their own investigations, we also hypothesized that they would become more proficient in scientific communication and would identify more strongly as scientists than the students in the RCL section.

In order to ensure that student expectations and workloads were comparable, instructors from the RCL and APS sections worked together to develop common assessments. A pre-course assessment comprised of 35 questions from published biology concept inventories (Haslam and Treagust, 1987; Treagust, 1988; Bowling et al., 2008; Garvin-Doxas and Klymkowsky, 2008; Shi et al., 2010) was given to students in the RCL and APS sections on the first day of class. Questions that tested each of the five core concepts of *Vision and Change* (Evolution, Structure/Function, Information Flow, Energy Transformation, Systems) were specifically selected for the pre-course assessment. Although a concept assessment instrument is intended to be given in its entirety and not as part of a larger survey, our goal was only to assess the knowledge base of our incoming students to compare with post-course scores, and not to be used in comparison with other groups. The same questions were included in the final exams for each class after the term in which the relevant material was covered. Note that pre and post assessments were not returned to students, nor were answers discussed with them. Students were also given the Experimental Design Ability Test (EDAT) at the beginning and end of the course, using a written format and pre-determined grading rubric (Sirum and Hamburg, 2011). Statistical significance was determined by Student's T-test.

Students in both sections used the same textbook, took identical online weekly quizzes, were given the same number and type of assessments, and answered a common set of questions on final exams. Additionally, instructors gave section-specific surveys to capture student perceptions during the year. The RCL section was given an online survey using a modified Student Assessment of Learning Gains (SALG) instrument (Seymour et al., 2007). Students were asked, using Likert-scale responses, how the structure of the course impacted their learning. Students in both sections were also asked to describe the "best" part of their respective biology courses. These open-ended responses were analyzed using content analysis which allowed us to "discover and describe the focus" of each section (Weber, 1990). Student responses were analyzed using an inductive strategy; no assumptions were made about students' ideas, rather, an emergent coding scheme was generated by two researchers through several rounds of iterative coding (Otero and Harlow, 2009).

In order to assess how APS students were participating in the NB annotation sessions, posts and comments were analyzed and coded using a deductive scheme (Wright et al., 2013).

Finally, the 2012-13 cohorts were tracked in their current courses in the 2013-14 academic year. Laboratory quizzes and exam grades were obtained from a Cell and Molecular biology course as well as a Microbiology course. Statistical significance was determined by Student's T-test.

Analysis and Findings

As shown in Figure 1, the APS students demonstrated significantly more prior knowledge and a narrower range of ability on the pre-course survey (results of t-test: $p = 6 \times 10^{-5}$). The average scores were 56.4% (SD 7.1, range 40-71) for APS and 46.7% (SD 14.5, range 17-80) for RCL. The dramatic difference was not surprising because students with AP credit were expected to have a more consistently rigorous background in biology than students coming from a wide range of high school courses.

Students did not receive pre-course assessments back, nor were the questions ever discussed directly in class. In order to measure normalized learning gains, the same pre-course questions were incorporated into the Fall and Winter term final exams (Figure 2). (Note that only the questions pertaining to each term's material were included.) By comparing pre and post-test averages for RCL and APS sections we concluded that students in both sections made significant improvements in their biology content knowledge. Even though the RCL students had lower pre and post-course scores compared to the APS students, normalized learning gains for the fall term were calculated at 43% for *each section* and 37% for *each section* in the winter term. We conclude that students in the APS section were not negatively impacted by the design of the course; they learned even though material from the textbook was not explicitly covered by the instructor during class time.

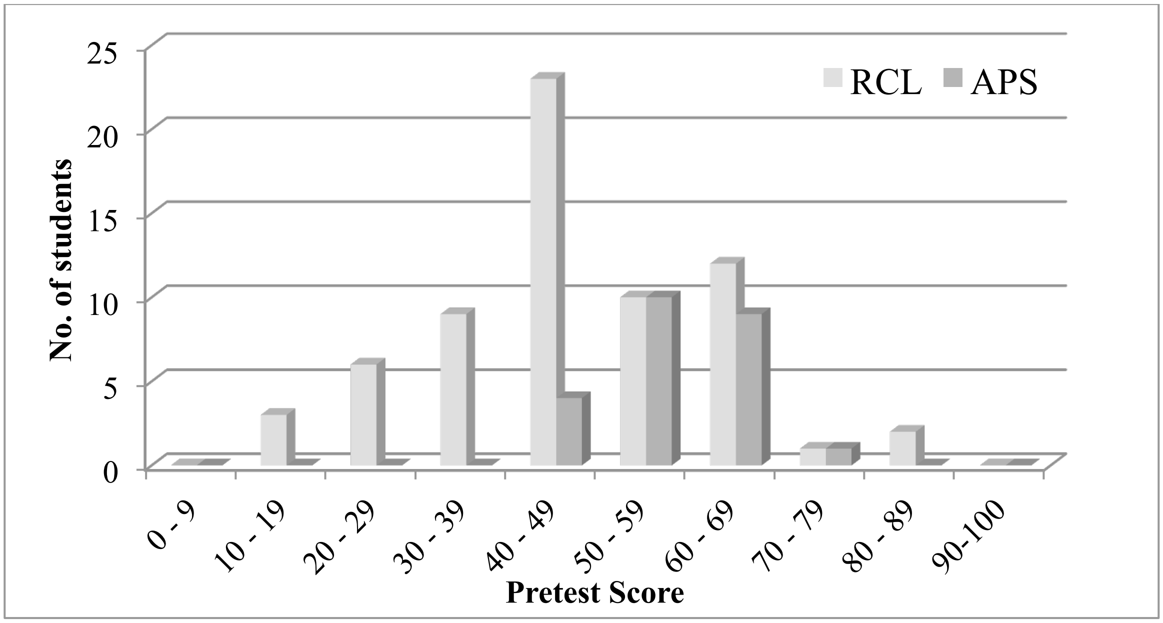

Figure 1. **Students in the APS section performed better on the pre-course biology concept assessment test than students in the RCL section.** Average score of APS students (N=66) was 10 points higher than RCL students (N=24), and their range was half the size.

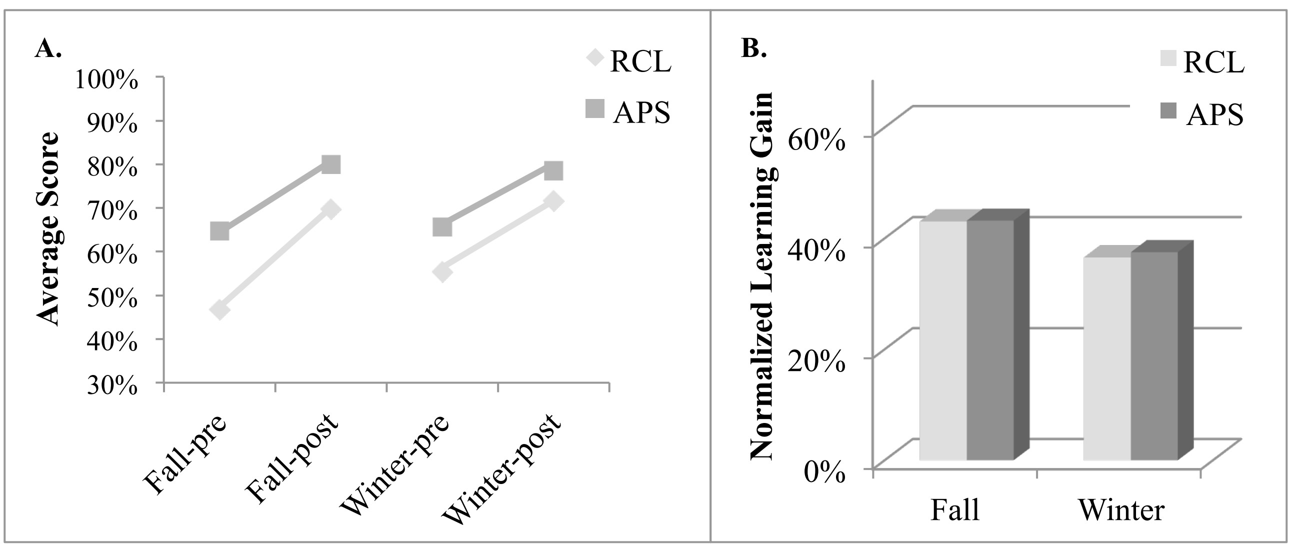

Figure 2. Normalized learning gains demonstrate comparable gains by both APS and RCL students. A) Raw scores, **B)** Normalized gains. Concepts tested in Fall pertained to cell and molecular biology, while concepts in Winter pertained to development and evolution.

Both RCL and APS emphasized experimental design in the laboratory. In order to assess gains in the ability of students to design an experiment, Part I of the Experimental Design Ability Test (EDAT) was administered to students during the first two weeks of the Fall term (pre) while Part II (post) of the EDAT was administered to APS and RCL students during the last two weeks of the Spring term. After completion of the entire year-long course, all EDATs were scored (0-10) by two raters using the published grading rubric. As shown in Figure 3, RCL students dramatically improved in their experimental design ability, with post-course EDATs scores significantly higher than pre-course scores ($p=10^{-5}$). Unfortunately APS pretests were unavailable, so gains could be not be calculated for the APS students; however, our analysis revealed that post-course EDAT scores were slightly higher than post-course scores of RCL students ($p=0.026$).

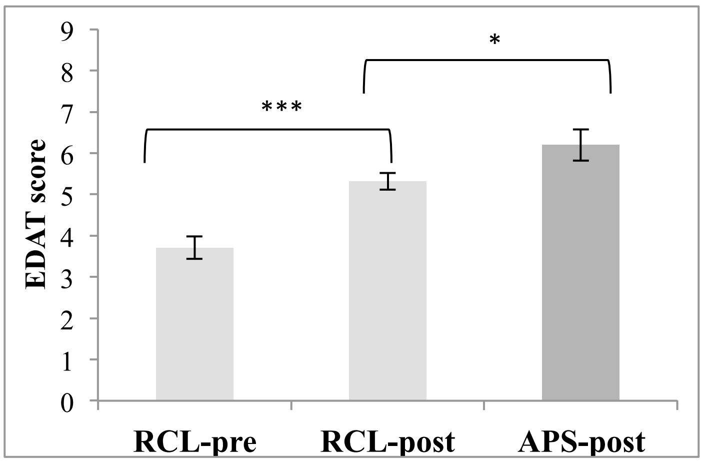

Figure 3. RCL students significantly improved in experimental design ability. Pre and post-course EDAT scores were calculated for RCL students while post-course EDAT scores were obtained from APS students (*, $p<0.05$; ***, $p<0.001$). Pretest data was not available for the APS class.

In order to assess student perceptions of the course, all students were asked, in an online survey format, "what was the best part" of their respective biology courses. Open ended responses were transcribed and coded by two raters to capture the major themes, which are presented in Table 2.

Table 2. Student responses to open-ended question about "the best part" of the course.

What was the best part of APS?	
Hands-on lab experience	64.7%
Learning how to become a scientist/doing "real science"	52.9%
Tailored learning experience	23.5%
Format better than a traditional class	23.5%

What was the best part of RCL?	
Learning environment	72.2%
Hands-on lab experience	22.2%
Connection between class and lab	16.7%

LESSONS LEARNED FROM THE FIRST YEAR IMPLEMENTATION OF A TWO-TRACK, REFORMED INTRODUCTORY BIOLOGY COURSE

The majority of students in the APS section (65%) listed the “hands-on lab experience” as the best part of their course. Since the APS students were in a laboratory-intensive course, these results were reassuring but not surprising. Consistent with our hypothesis that APS students would identify as scientists, though, we found that the majority (53%) of APS students included comments that were categorized as “learning how to become a scientist/doing real science.” While this data is self-reported, we interpret these statements to be evidence of inculcation into the discipline; students in the APS section self-identified with the scientific community. Some sample responses are shown below:

> *The freedom to do individual research and feel important to the science community*
>
> *The lab work was the most rewarding part of AP Scholars in my opinion. It was an opportunity to express ourselves as real scientists and learn skills that we otherwise would not have*
>
> *I like doing all the different lab activities and actually make us feel like we're real scientists and we're doing this for a purpose.*

While 22% of students in the RCL section praised the hands-on lab experience and found the connection between class and lab to be the best parts of the class, evidence of inculcation was absent from their responses, different from the APS students. Interestingly, 73% of the RCL comments reported that the learning environment was the best part about the course. Students in the RCL section seemed to recognize and appreciate the active learning components and liked the focus on concepts instead of details. Sample responses are shown below:

> *The case studies helped to solidify the topics discussed in class, and applied the current topic to a real-world situation. It felt like we were learning more than just terms.*
>
> *“Clicker questions” kept me alert and helped me learn more effectively in class (I noticed I would actually remember a solution to a question better if I had previously gotten it wrong on a clicker question)*
>
> *I had to learn how to think outside of the box, and apply my knowledge to real life. It was hard at first because I'm used to different style of teaching...but I think it worked out very well.*

The APS students also appreciated various online components of the course. On an open-ended survey, all respondents spoke very highly of using the NB system to read and participate in virtual discussions, and they liked the Facebook community (although some preferred not to be graded on Facebook contributions). In order to gain more insight into how the APS students used NB, the student-generated online comments and posts were analyzed for content. We identified three major themes emerged from the analysis; (1) Observational comments about science, (2) Questions/Answers about interpretation and (3) Knowledge Synthesis. We defined these categories in the following manner:

1. Observational comments about science: These were annotations not directly related to analysis of the paper but showed students' interest in the topic or its relationship to other biological topics. Students wrote statement such as:

   I started to think that we were only looking at one branch of biology but now that I read this article, I realize that this type of study can apply to all sorts of branches of biology. It makes me really excited that we get to be the new generation of scientists that can build off of this study and create our own. It's all so fascinating.

2. Question/Answer about interpretation: These were annotations that asked about or clarified a specific term or concept in the paper. Students wrote statements such as:

   I was slightly confused when the authors kept mentioning quantitative versus qualitative data and it simply meant that they were collecting data that they could measure rather than just see. Quantitative would include growth rate, body length, tail length, and all the other factors that could possibly be measured. Qualitative would be if they were testing to see if the species changed color or something similar to that in response to the predator. I just thought I would put it simply in case anyone else was confused about this.

3. Knowledge Synthesis: These annotations indicated that new knowledge was synthesized as a result of making connections between topics or data presented in the paper. Knowledge synthesis is a higher-order cognitive skill that shows a deeper learning (Furst, 1981; Krathwohl, 2002). For this category comments such as the following were considered:

   The fact that they got all of the tadpoles from the same foam nest probably helped lower the differences in the genomes of the tadpoles limiting all differences to epigenetics. This was a very intelligent way to run the experiment.

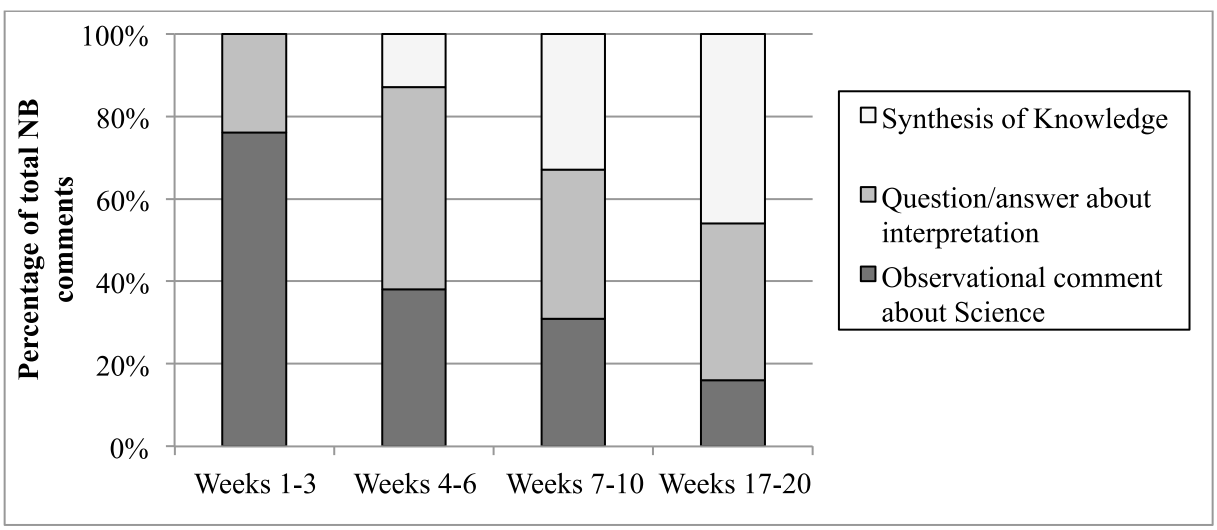

Figure 4. APS students demonstrate higher-order thinking while discussion the primary literature. During the first few weeks of the term students mainly made observational comments but shifted to more instances of knowledge synthesis by the end.

Comments were quantified and correlated with time (weeks) during the term. As shown in Figure 4, students annotated differently as the course progressed. We found that APS students made fewer observational comments but more synthesis-type comments in the later weeks of the term, suggesting that our APS students gained a higher level of comfort and expertise in terms of analyzing and discussing the primary literature. These were learning goals of the APS class that were not explicitly included in the RCL experience.

After the course was finished, all students in the RCL section were invited to participate in an online survey using a modified SALG instrument (Seymour et al., 2007). Students were asked, to rate on a Likert scale how the RCL course structure impacted their own learning (Figure 5). The majority of the students agreed that the structure of the course helped them make connections between topics, apply concepts to real-world problems, improve their critical thinking and problem solving ability and improve their confidence to work in a laboratory. The majority of the RCL students also agreed that the structure of the course encouraged them to attend class, participate in discussion and ask questions.

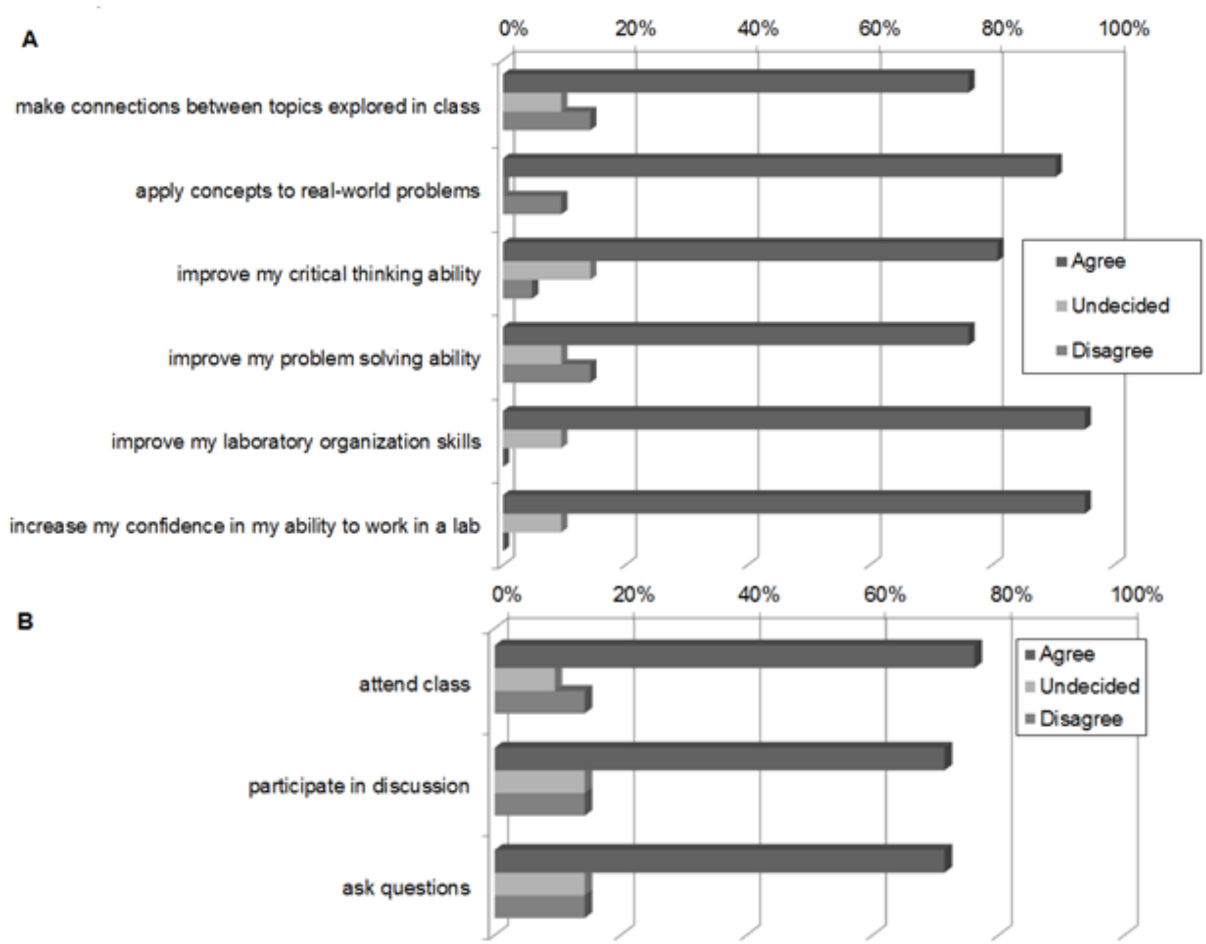

Figure 5 (continued). RCL students reported positive learning gains using the Student Assessment of Learning Gains (SALG) survey tool. Student responses (n=23) to (A) "The structure of this course helped me…" and (B) "The structure of this course encouraged me to …" using Likert scales.

Students in both the RCL and APS section are currently being tracked in their second year biology courses to help the research team determine positive or negative long-term effects from the Introductory Biology course. Since many biology students take Cell and Molecular Biology and/or Microbiology during the Fall term, these courses were used to measure progress of both cohorts of students (Figure 6). Other students who take those courses include those who took a traditional general biology course at RIT or transferred credit from another institution. Many of them are upper-level students who have taken additional biology courses. APS students continue to outperform RCL students in both courses, while RCL students are performing at the same level as the other students in Cell & Molecular. Both cohorts are doing better than the other students in Microbiology (combined RCL/APS vs. others, p=0.025), almost all of whom are upperclassmen. It is interesting to note that the Cell & Molecular course is taught in a more traditional, instructor-centered format and fact-based assessments. On the other hand, the Microbiology course is taught using student-centered pedagogies, with concept-based and problem-solving assessments. Clearly the APS students excel in either venue—but this is not surprising, as the best students usually can adapt to any teaching style. The RCL students on the other hand, seem to be better prepared for the reformed classroom than for the traditional one.

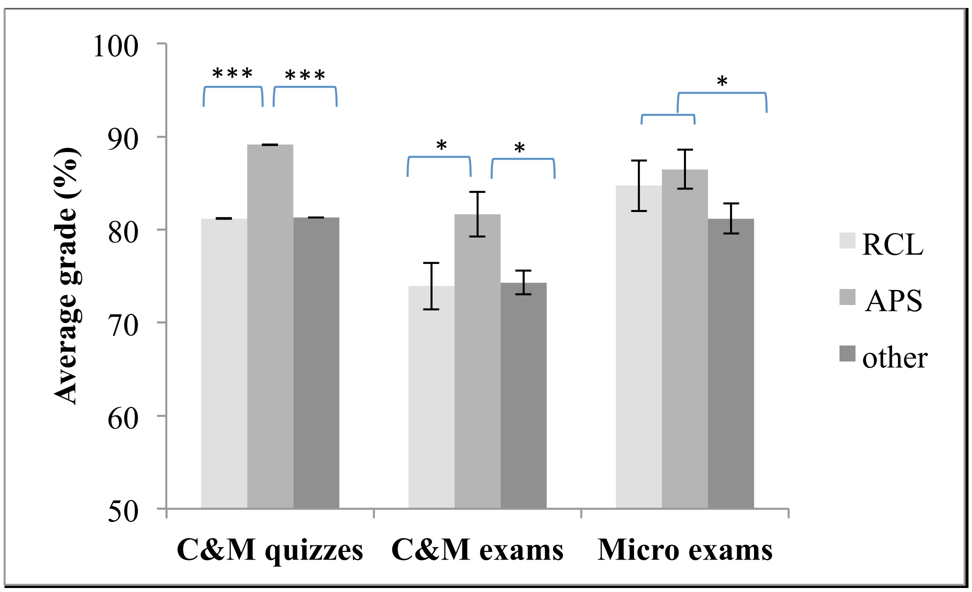

Figure 6. APS students perform at a higher level in second-year courses. Analysis of laboratory quizzes and exam grades from Cell and Molecular Biology (C&M) reveal that APS (N=16) students have a statistically higher exam average compared to RCL (N=22, p=0.032) and other students (N=95; p=0.012). The RCL students perform comparably to the other students, most of whom took a traditional biology course. In Microbiology (Micro), there are fewer students, but the APS (N=7) have the highest average, followed by RCL (N=13). Due to the small numbers we combined all students in the reformed courses to compare against the remainder of the Micro class (p=0.025). It is worth noting that the vast majority of other students in that class (N=46) are juniors and seniors in the same majors.

LESSONS LEARNED FROM THE FIRST YEAR IMPLEMENTATION OF A TWO-TRACK, REFORMED INTRODUCTORY BIOLOGY COURSE

Contribution/General Interest

This study provides further evidence that guided inquiry is an effective course design for introductory biology and provides a model for others to follow. We investigated two different methods for implementing guided inquiry, one that was a student-driven investigative research experience (APS) and the other that relied more heavily on topics presented in an Introductory Biology textbook, but was still based on active learning and constructivist theory (RCL). Both groups showed significant learning gains, an improvement in experimental design ability as well as satisfaction with the course. Furthermore, dividing the Introduction to Biology course into sections based on incoming preparation benefitted *all students*. Students with AP credit generally had higher background knowledge and rose to the challenge of becoming practicing biologists from the first day of the course. Students in the RCL section generally needed more time and practice with biology content, but they were still challenged to learn conceptually with student-centered, active learning pedagogies. Plus, students in both sections seem to have been well prepared for their next courses, even though less content was presented in class.

In addition to our successes with the course redesign, we learned some important lessons that may benefit others in similar situations. First, we realized that it was important to have a single coordinator of all sections, who could run monthly instructor meetings, facilitate sharing of pedagogical strategies and materials, ensure that all assessments were given to all groups, collect and record all data. Second, we learned that it was difficult to design a pre-course assessment without a complete plan for the course. Our pretest ended up being most appropriate for the fall and winter terms, because that part was most fully planned at the beginning of the year. Now that the course has been taught once already, we have also improved our pre-course assessment to make sure that concepts from the entire year-long course were included. This will allow for more accurate assessment of learning gains and more precise comparisons between groups.

We have also slightly revised any question stems or answer choices that did not meet criteria for well-constructed multiple choice questions (Haladyna et al., 2002; McCoubrie, 2004). Student responses to surveys were extremely helpful in determining what to change and what to keep in the next iteration of the course. We found that several students in the 2012-13 cohort, were unhappy because they felt they were placed in the APS section without being asked. This year the RCL and APS instructors met with the incoming freshman during orientation and described both sections of the course. Students in both sections responded enthusiastically and seemed to appreciate the face-time with all instructors before the semester began. We think that all students currently enrolled in the 2013-14 APS section have a high level of buy-in and ownership of the course because they actively chose to participate. The APS course is now being highlighted in open-houses for recruitment of future freshman classes.

This year we have reduced the number of online activities for the APS section, since students complained of being overburdened and finding some of them redundant. In order to improve consistency of content with the RCL course, we have added cinélectures--short (10 minutes or less) instructional videos to be viewed online--which provide a venue for focused content delivery outside of class time. The 2013-14 cohort is continuing with the broad theme of “vanishing amphibians” because the topic is accessible to students and investigations at all levels of biology (i.e. molecular biology through ecosystems) is possible. The current 2013-14 APS cohort, for example, has identified over a dozen species of bacteria found on local amphibians using DNA sequencing technologies. The APS students have also investigated the production of the anti-microbial/anti-fungal compound, violacein, from *Janthinobacterium lividum.* The APS students were so excited about this compound that they are currently in progress of cloning the genes of the violacein pathway from *J. lividum* into *E. coli*.

Another piece of advice is to have a team of instructors (for both the RCL and APS sections) who are student-centered and flexible. From our experience we have learned that students in the RCL section have larger gaps in biology content and conceptual knowledge upon entering college. The RCL instructor will need to create activities and assessments to help students make connections and build on (somewhat shaky) pre-existing knowledge. While the APS course is investigative, the APS instructor will need to have a big-picture plan, for at least the first few weeks of the term, so laboratory specialized reagents and equipment could be organized in advance. Guiding the students towards a microbiology-related project seems is, in our opinion, a good place to begin. APS students should be responsible, as much as possible, for preparing their own laboratory reagents and an instructor will need to factor in the time it takes for these preparations.

Finally, we feel that reform cannot be limited to the freshman sequence. If students are to become critical thinkers and effective scientists, the entire curriculum should be revamped to focus on concepts rather than facts and investigation over memorization, as promoted by many leaders in the field of biology education (AAAS, 2009). We will continue to track each cohort to see how their performance compares after preparation in our two tracks. In addition to the data presened here, we have received anecdotal feedback that the reformed instruction courses' students feel more prepared than their peers in their second year courses, and many of them are participating in mentored undergraduate research. We have also received informal feedback that some of them are bored by traditional lectures and prefer their freshman experience to their current courses. The students made so much progress in their first year that it would be a shame to see that momentum lost.

In conclusion, we believe that the two-track Introductory Biology sequence could work in a number of settings and may be a way for institutions to adopt active-learning pedagogies and investigative projects into their curriculum.

References

AAAS (2009). Vision and Change in Undergraduate Biology Education: A Call to Action (Washington, D.C.: American Association for the Advancement of Science).

Armbruster, P., Patel, M., Johnson, E., and Weiss, M. (2009). Active Learning and Student-centered Pedagogy Improve Student Attitudes and Performance in Introductory Biology. CBE-Life Sci. Educ. *8*, 203–213.

Bowling, B.V., Acra, E.E., Wang, L., Myers, M.F., Dean, G.E., Markle, G.C., Moskalik, C.L., and Huether, C.A. (2008). Development and Evaluation of a Genetics Literacy Assessment Instrument for Undergraduates. Genetics *178*, 15–22.

Campbell, A.M., Heyer, L.J., Paradise, C.J., Barsoum, M.J., and Sellers, P.J. (2011). Integrating Concepts in Biology Utilizes the First Principles of Learning (Minneapolis, MN).

Fisher, M.C., Garner, T.W.J., and Walker, S.F. (2009). Global emergence of Batrachochytrium dendrobatidis and amphibian chytridiomycosis in space, time, and host. Annu. Rev. Microbiol. *63*, 291–310.

Furst, E.J. (1981). Bloom's Taxonomy of Educational Objectives for the Cognitive Domain: Philosophical and Educational Issues. Rev. Educ. Res. *51*, 441–453.

Garvin-Doxas, K., and Klymkowsky, M.W. (2008). Understanding Randomness and its Impact on Student Learning: Lessons Learned from Building the Biology Concept Inventory (BCI). CBE-Life Sci. Educ. *7*, 227 –233.

Haladyna, T., Downing, S., and Rodriguez, M. (2002). A Review of Multiple-Choice Item-Writing Guidelines for Classroom Assessment. Appl. Meas. Educ. *15*, 309–334.

Haslam, F., and Treagust, D.F. (1987). Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. J. Biol. Educ. *21*, 203–211.

Hillis, D.M. (2012). Principles of life (Sunderland, MA; Gordonsville, VA: Sinauer Associates□; W.H. Freeman).

Kilpatrick, A.M., Briggs, C.J., and Daszak, P. (2010). The ecology and impact of chytridiomycosis: an emerging disease of amphibians. Trends Ecol. Evol. *25*, 109–118.

Krathwohl, D.R. (2002). A Revision of Bloom's Taxonomy: An Overview. Theory Pract. *41*, 212–218.

McCoubrie, P. (2004). Improving the fairness of multiple-choice questions: a literature review. Med. Teach. *26*, 709–712.

McDaniel, C.N., Lister, B.C., Hanna, M.H., and Roy, H. (2007). Increased Learning Observed in Redesigned Introductory Biology Course that Employed Web-enhanced, Interactive Pedagogy. CBE Life Sci. Educ. *6*, 243–249.

Otero, V.K., and Harlow, D.B. (2009). Getting Started in Qualitative Physics Education Research. In Getting Started in PER, (American Association of Physics Teachers), pp. 1–66.

Seymour, E., Wiese, D., Hunter, A.-B., and Daffinrud, S. (2007). Creating a Better Mousetrap: On-line Student Assessment of their Learning Gains (San Francisco, CA).

Shi, J., Wood, W.B., Martin, J.M., Guild, N.A., Vicens, Q., and Knight, J.K. (2010). A Diagnostic Assessment for Introductory Molecular and Cell Biology. CBE-Life Sci. Educ. *9*, 453–461.

Sirum, K., and Hamburg, J. (2011). The Experimental Design Ability Test (EDAT). J. Coll. Biol. Teach. *37*, 8–15.

Treagust, D.F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. Int. J. Sci. Educ. *10*, 159–169.

Ueckert, C., Adams, A., and Lock, J. (2011). Redesigning a Large-Enrollment Introductory Biology Course. CBE-Life Sci. Educ. *10*, 164–174.

Weber, R.P. (1990). Basic Content Analysis (Newbury, California: SAGE Publicatoins, Inc.).

Wright, L.K., Zyto, S., Kargar, D., and Newman, D.L. (2013). Online Reading Informs Classroom Instruction and Promotes Collaborative Learning. J. Coll. Sci. Teach. *43*, 44–53.