Annotated Bibliography

Laboratory Teaching Examples in the Sciences

This resource of laboratory teaching examples in the Sciences is compiled from a search of educational databases and disciplinary journals for peer-reviewed articles published in English over the past few years. Forty articles were selected for inclusion based on their disciplinary relevance, pedagogical innovation and evidence of effectiveness. The value of all these examples lies in the ideas they present for reflection and critical discussion. Copies of all articles are available from the Office of Science Education (OSE). This compilation represents a work in progress that we intend adding to in the future. If you know of interesting examples, please contact the OSE Director, Marcy Slapcoff: marcy.slapcoff@mcgill.ca.

To assist in navigation, articles are grouped by discipline: Biology, Chemistry, Earth and Planetary Science, Geography, Psychology and Physics, and categorized by level: introductory [I] or upper [U] and pedagogical strategy: inquiry [IN] or large class [LC]. A final section includes examples of training programs for teaching assistants in Science laboratories. We recognize that laboratory teaching varies between departments and institutions. However, particular forms of innovative pedagogical design are often transferable to other contexts. An asterisk in the margin indicates examples we consider sufficiently detailed in terms of implementation and evaluation to assist in transfer to other courses and disciplines.

1 Biology

1.1 Online library tutorial [I, LC]

Barkley, M. (2018). The Library in the Laboratory: Implementing an Online Library Tutorial in a Freshman Biology Lab. *Issues in Science and Technology Librarianship*. DOI:10.5062/F45B00QH

This online library tutorial was developed (with reference to the work of two McGill University librarians) in the context of an introductory course covering the biological concepts surrounding evolution, diversity, and ecology required for all Biology undergraduate majors. The author is a Life and Health Sciences Librarian at the University of Dayton, Ohio, USA. The tutorial puts into practice many recommended features for keeping students engaged: information broken into segments, interactive questions, and flexibility in content access. Combining topics of database access and use, academic honesty, and proper citation techniques, it fills a discipline specific research need not generally met in the first year curriculum in the USA. By partnering with the Scientific Writing PreLab the tutorial has flexibility to connect articles with projects students will work on later in the semester. This example provides a case study of library-faculty partnership in creating and implementing resources.

http://www.istl.org/18-winter/tips.html

1.2 Student-designed experiments [I, IN]

Coker, J. S. (2017). Student-Designed Experiments: A Pedagogical Design for Introductory Science Labs. *Journal of College Science Teaching*, *46*(5), 14–19.

This study developed and evaluated a pedagogical design for introductory Biology labs for non-Science majors where students designed, carried out, analyzed, and presented their own experiments. The author is Director of the Elon Core Curriculum and an Associate Professor of Biology at Elon University in North Carolina, USA. Each module was 3 weeks long, allowing students to complete the entire experimental process 4 times over the course of the semester. Assessment included pre- and post-surveys, video analysis of group work, exit interviews, analysis of changes in lab reports across the semester, and instructor observations. Students rated their lab experiences highly, became more confident in using the scientific process, and improved in terms of scientific process and scientific reasoning. Students also learned science content, though the content varied from student to student.

https://eric.ed.gov/?id=EJ1142974

* Interdisciplinary research online [U, IN]

Lindh, J., Annerstedt, C., Besier, T., Matheson, G. O., & Rydmark, M. (2016). Evaluation of Parallel Authentic Research-Based Courses in Human Biology on Student Experiences at Stanford University and the University of Gothenburg. *Journal of the Scholarship of Teaching and Learning*, *16*(5), 70–91.

This is an example of researchers and teachers at Stanford University (USA) and the University of Gothenburg (Sweden) co-designing a ten-week interdisciplinary, research-based laboratory course in human biology to be taught online to undergraduate students (syllabus included). Essentials in the subject were taught during the first four weeks of the course. Subsequently, student groups at each university developed their own research questions, conducted live-streamed experiments remotely, processed their unique data with support from multiple interactive resources, cross-cultural collaboration and an interdisciplinary network of expert consultants, and presented original scientific results remotely. Student course-perceptions were evaluated using online questionnaires, reflective blogs, and observations. The course clearly improved student abilities to conduct research using laboratory experiments while learning theoretical basics. A comparison of pre- and post-course scores from student surveys showed that post-course student comfort levels with several research-related tasks increased radically. All participating staff generally agreed that the methods and tools were valuable in this type of course.

https://files.eric.ed.gov/fulltext/EJ1118779.pdf

1.3 Multi-week tree thinking curriculum [U, IN]

Novick, L. R., & Catley, K. M. (2018). Teaching Tree Thinking in an Upper Level Organismal Biology Course: Testing the Effectiveness of a Multifaceted Curriculum. *Journal of Biological Education*, *52*(1), 66–78.

This article reports on continued efforts to create, implement and evaluate a research-based tree-thinking curriculum and assessment tool. The authors are from the Department of Psychology and Human Development, Vanderbilt University, Nashville, and the Department of Biology, Western Carolina University, Cullowhee, USA. In the present study, several parts of an upper level organismal biology curriculum supported the goal of teaching how to interpret cladograms and reason with the information depicted therein: instructional booklet, initial lectures and phylogenetics lab. Other parts supported the more general goal of utilizing tree thinking to more fully appreciate the connectivity and interdependence of all life: later lectures, dinner table cladogram activity, and evolution in action lab. Biology students (n=17) enrolled in the course received the multi-week tree-thinking curriculum with learning assessed by comparing pre- and post-test scores. Quantitatively, large gains were found in tree-thinking abilities. Results also provided qualitative evidence of succeeding with the more general goal of helping students to appreciate the interconnectedness of Earth's biodiversity.

https://www.tandfonline.com/doi/abs/10.1080/00219266.2017.1285804

1.4 Comparison of virtual and face-to-face laboratories [I, LC]

Reece, A. J., & Butler, M. B. (2017). Virtually the Same: A Comparison of STEM Students' Content Knowledge, Course Performance, and Motivation to Learn in Virtual and Face-to-Face Introductory Biology Laboratories. Research and Teaching. *Journal of College Science Teaching*, *46*(3), 83–89.

The LearnSmart Labs by McGraw Hill Higher Education (New York, NY) used in this research project were comparable to the face-to-face labs in a large introductory Biology course. The authors are from the

Biology Department at California State University and the School of Teaching, Learning, and Leadership at the University of Central Florida, USA. Undergraduate students (*n*=300) were randomly assigned into one experimental group (virtual labs) and one comparison group (face-to-face labs). They completed a laboratory content test and the Biology Motivation Questionnaire II at the beginning and end of the semester. Final course grades were also obtained. Analyses revealed no significant differences in learning gains between students in the face-to-face and virtual simulation labs on the content test and final course grades. Two thirds of the students experienced a decline in motivation to learn biology over the semester, but no significant difference was found between the two groups.

https://eric.ed.gov/?id=EJ1127368

2 Chemistry

2.1 Pre-lab activities [I, LC]

Agustian, H. J., & Seery, M. K. (2017). Reasserting the role of pre-laboratory activities in chemistry education: A proposed framework for their design. *Chemistry Education Research and Practice*, *18*, 518–532.

This review article summarizes over 60 reports and research articles on pre-laboratory activities in higher education chemistry. The authors are professors at the School of Chemistry, University of Edinburgh, UK. A framework for designing pre-laboratory activities is proposed that aligns with the principles of cognitive load theory, specifically supporting a complex learning task by scaffolding and providing information in advance. Of particular relevance is the nature of information provided in advance (supportive) and that provided just in time (procedural). Guidelines are proposed for those wishing to incorporate pre-laboratory activities into their laboratory curriculum, for example, embed activities in the overall laboratory learning experience, focus attention on the whole task drawing attention to the overall strategy and approaches, focus on supportive information, and address the affective domain (improve confidence and motivation through student-generated resources and conversation).

https://pubs.rsc.org/en/content/articlelanding/2017/rp/c7rp00140a#!divAbstract

2.2 Discovery-based research experience [U, IN]

Baar, M. R. (2018). Research Experience for the Organic Chemistry Laboratory: A Student-Centered Optimization of A Microwave-Enhanced Williamson Ether Synthesis and GC Analysis. *Journal of Chemical Education*, *95*(7), 1235–1237.

This example of an Organic Chemistry experiment moves a ‘cook book’ laboratory to a discovery-based one through rapid analysis. The author is a Chemistry Professor in the Department of Chemistry at Muhlenberg College, Pennsylvania, USA. Using one monomode microwave oven and one GC instrument for every 5 students, data (related to Williamson ether synthesis) can be reviewed, new variables proposed, and the experiment run and re-analysed under revised conditions, all within a 3 hour laboratory period. Formal assessment of students’ initial and revised plans showed improvement. In their laboratory reports, students explained the reasoning behind their team’s plans and their success or lack thereof. They were asked questions concerning their understanding of the experiment’s goals in their weekly lab quiz. Individually, students also had to analyze data from the entire class and propose a new trial. Supporting Information of the experimental procedures is included as well as student report guidelines and complete results from student experiments over a 3-year period.

https://pubs.acs.org/doi/10.1021/acs.jchemed.7b00592

2.3 Inquiry-based module [U, IN]

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Brown, J. A. L. (2016). Evaluating the Effectiveness of a Practical Inquiry-Based Learning Bioinformatics Module on Undergraduate Student Engagement and Applied Skills. *Biochemistry and Molecular Biology Education*, *44*(3), 304–313.

This intervention evaluates the success of a new module in practical bioinformatics designed to incorporate use of the most up-to-date, relevant and widely used suites of software tools and databases (list included). The author is a professor in the Department of Biochemistry, School of Natural Sciences, and the Discipline of Surgery, School of Medicine, Lambe Institute for Translational Research, at the National University of Galway, Ireland. Third year undergraduate biotechnology students (n=20–35) led a laboratory-based research project within a framework of inquiry. Students were divided into small collaborative groups, each with a distinctive central theme. The module was evaluated by assessing the quality and originality of the students' targets through individual reports (using a rubric shared with students) and performance on pre- and post-module quizzes (not contributing to the final grade). A highly significant increase was observed when answering questions that required process-specific (applied) knowledge. The high quality of the submitted reports and the positive comments received in a post-module survey indicated that students were very engaged in the scientific process.

https://www.ncbi.nlm.nih.gov/pubmed/27161812

* 2.4 Blended strategies [I, LC]

Burchett, S., Hayes, J., Pfaff, A., Satterfield, E. T., Skyles, A., & Woelk, K. (2016). Piloting Blended Strategies to Resolve Laboratory Capacity Issues in a First-Semester General Chemistry Course. *Journal of Chemical Education*, *93*(7), 1217–1222.

Blended strategies enable learners to engage in structured activities outside the traditional learning environment, in this case the traditional laboratory. This example demonstrates collaboration among 6 Chemistry professors from the Missouri University of Science and Technology and State Fair Community College in Missouri, USA. Concepts were identified from a first-semester general chemistry laboratory course that would best align with the lecture and then activities developed that allowed students to rotate between In-the-Lab and In-the-Commons work areas (with indirect supervision in the latter, i.e., more independent learning). The " pilot" included a face-to-face section (n=23) and a blended section (n=24) with the same teaching assistants employed to reduce variables and bias. Average pre/post test scores showed no significant difference between the two delivery modes. The only disparity was between drop rates: from 11% for traditional delivery to 5% for blended. These results validate adoption of blended strategies for doubling course capacity without compromising the hands-on nature of traditional laboratory activities. Both the intervention and the research are sufficiently detailed to facilitate transfer.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.6b00078

2.5 Structured experimental activities [I, LC]

Collison, C. G., Kim, T., Cody, J., Anderson, J., Edelbach, B., Marmor, W., … Niziol, J. (2018). Transforming the Organic Chemistry Lab Experience: Design, Implementation, and Evaluation of Reformed Experimental Activities--REActivities. *Journal of Chemical Education*, *95*(1), 55–61.

This example describes the conversion of a traditional organic laboratory by one infused with aspects of guided-inquiry using a structured teaching method (REActivities). The authors comprise a large collaboration among Chemistry professors from the Rochester Institute of Technology and Monroe Community College in New York State, USA. The method is described in the context of a curriculum example. Essentially, it involves linking lecture and lab material, using a communal pool of compounds, repeated techniques, and the requirement for students to use previous notebook entries. It excludes any pre-lab lecture by the instructor but rather incorporates contextually timed student partner work and reflection prompts in a student workbook. Evaluation comparing REActivities with expository delivery uses a teaching observation protocol correlated between different instructors and different institutions. Scores were appreciably higher for the REActivities method and fidelity of implementation was established.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.7b00234

* 2.6 Integrated course design [U, IN]

Evans, H. G., Heyl, D. L., & Liggit, P. (2016). Team-Based Learning, Faculty Research, and Grant Writing Bring Significant Learning Experiences to an Undergraduate Biochemistry Laboratory Course. *Journal of Chemical Education*, *93*(6), 1027–1033.

To foster student development as scientists in academia, this Biochemistry laboratory course employs an integrated course design that uses faculty research as a teaching tool, team-based learning, and a mini grant proposal as capstone project. The authors are a professor in the Department of Chemistry and staff in the Faculty Development Center at Eastern Michigan University, USA. A variety of practices are included, for example, discussion of academic success, peer-critique, presenting results to a scientific and non-scientific audience, and disseminating work through presentations and publications. Student evaluations analyzed over a 9-year period show the course was rated higher overall compared to similar laboratory courses in the program. Participation is crucial and this requires instructors striking the right balance between supporting students and encouraging independent learning. This is a well-documented example with sufficient detail of the learning template to facilitate transfer.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.5b00854

2.7 Integrating ongoing research into an authentic assignment [I, IN]

Hansen, S. J. R., Zhu, J., Karch, J. M., Sorrento, C. M., Ulichny, J. C., & Kaufman, L. J. (2016). Bridging the Gap between Instructional and Research Laboratories: Teaching Data Analysis Software Skills through the Manipulation of Original Research Data. *Journal of Chemical Education*, *93*(4), 663–668.

This article demonstrates successful integration of ongoing research into an instructional laboratory course in the context of teaching basic data analysis skills using a Microsoft Excel-based activity. The research team is from the Department of Chemistry at Columbia University, New York. A graduate student adapted an article by the first author into an assignment that required undergraduate students to engage with the data by performing a series of analytical tasks and collaborative work. The assignment was first pilot tested in a summer course with a small class size (n=29) and then with larger classes sizes over three semesters (n=125, n=272, n=124). Multiple iterations allowed exploration of different pedagogical approaches. Results from survey data showed improvements in students' self-reported pre- and post Excel ability, with greater gains showed by students who were most positive about the assignment. This is an example of providing opportunities for graduate students to gain valuable curriculum development experience at the same time as challenging undergraduate students to read complex literature while practicing data analysis techniques with little to no support. Recommendations are included for adapting a similar exercise for a course.

http://www.columbia.edu/cu/chemistry/groups/kaufman/publication%20pdfs/JChemEd.pdf

2.8 Design your own workup assignment [I, IN]

Mistry, N., Fitzpatrick, C., & Gorman, S. (2016). Design Your Own Workup: A Guided-Inquiry Experiment for Introductory Organic Laboratory Courses. *Journal of Chemical Education*, *93*(6), 1091–1095.

This experiment was part of a 9 hour practical introduced to a first-year undergraduate laboratory course for Chemistry and Medicinal Chemistry majors structured as part of a rotational laboratory course design. The authors are professors in the School of Chemistry at the University of Leeds, U.K. Each group performing the experiment was given a different mixture to purify in the following sequence: pre-lab quiz (10%); design workup (in the form of a flowchart); check procedure (with the help of a TA); purify mixture; assessment and reflection. Results (*n*=135) showed a high average score for the pre-lab quiz, 90−95% of students designed a flowchart that would have separated the compounds, and the average final grade for the workup section was 73.8% (similar to the overall grades achieved from other experiments in the course). Feedback (*n*=58) indicated that the experiment required students to solve problems and improve their problem-solving ability. The authors conclude that the experiment is easy and cost efficient to create while having learning gains that could not be achieved in a recipe-based experiment.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.5b00691

2.9 A writing-to-learn method [I, IN]

Van Duzor, A. G. (2016). Using Self-Explanations in the Laboratory to Connect Theory and Practice: The Decision/Explanation/Observation/Inference Writing Method. *Journal of Chemical Education, 93*(10), 1725–1730.

This example describes implementation of a laboratory writing-to-learn method (DEOI) that emphasizes student self-explanations of procedures and outcomes. The author is from the Department of Chemistry, Physics, and Engineering Studies, Chicago State University, USA. The DEOI method expands traditional laboratory report writing to four columns: Decision, Explanation, Observation, and Inference. Students are required to consider the chemical reasons for procedural actions in the “explanation” column and to interpret data and draw conclusions in the “inference” column. Implementation took place in organic chemistry laboratories at two very different universities. The action research method was used that involved the instructor serving as participant observer in the classroom, analyzing student laboratory reports, and conducting semi structured interviews. Emergent themes regarding students’ perceptions of the DEOI method and their ability to link theory and practices suggests it helps a diversity of students understand laboratory procedures and encourages engagement. Supporting information is included on introducing the DEOI method to students, using the method in the laboratory, and grading.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.6b00093

2.10 Peer-led team learning [U, IN]

Williams, J. L., Miller, M. E., Avitabile, B. C., Burrow, D. L., Schmittou, A. N., Mann, M. K., & Hiatt, L. A. (2017). Teaching Students to Be Instrumental in Analysis: Peer-Led Team Learning in the Instrumental Laboratory. *Journal of Chemical Education*, *94*(12), 1889–1895.

This example describes a peer-led team learning model developed to mitigate issues with traditional instrumental analysis courses and give students in-depth experiences operating and troubleshooting six common instruments. The authors are from the Department of Chemistry at Austin Peay State University in Tennessee, USA. Electronic cigarette solutions were chosen for all lab work because of their current relevance and to let students focus on the instruments rather than chemical details. The class was divided into five groups of two (*n*=10). Each group became the “class expert” on their assigned instrument responsible for teaching their peers how to utilize their instrument for experimentation as well as writing an operation and procedure manual. Each student rotated through their peer’s instruments, learned to apply the knowledge they gained from one instrument to others, while they answered questions from peers. Oral quizzes were used to assess verbal reasoning skills. Although a small sample, results suggest peer-led team learning can be successful in developing troubleshooting and communication skills -

foundational tools for chemists. In a post semester survey, students expressed confidence in solving problems on their own and they no longer felt afraid to try something that might not work.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.7b00285

3 Earth and Planetary Science

3.1 Demonstrating the importance of a laboratory section [I, LC]

Forcino, F. L. (2013). The Importance of a Laboratory Section on Student Learning Outcomes in a University Introductory Earth Science Course. *Journal of Geoscience Education*, *61*, 213–221.

This study demonstrates the importance of having a laboratory component of an introductory-level, university Earth science course. The author is from the Department of Earth and Atmospheric Sciences, University of Alberta in Edmonton, Canada. Students' conceptual knowledge outcomes from laboratory sections were measured by administering an independent concept inventory (a modified version of the Geoscience Concept Inventory) at the beginning and end of two courses: lecture with laboratory, and lecture-only (a brief description of both is included). Students in both courses demonstrated a significant increase in inventory scores. The mean increase for the course with laboratory (pre n=74, post n=56) was 33% greater than for the lecture-only course (pre n=354, post n=253). There is no evidence that a student more adept at science enrolled in one course instead of the other and the same two instructors taught the same material in both courses. However, one notable difference between the two courses was that the lecture-only course was intensive, while the course with a lab spanned a full academic term. The author concludes that since research exists demonstrating time-shortened courses produce the same increase in student concept knowledge as traditional-length courses, the inclusion of the laboratory most likely led to greater learning gains.

https://files.eric.ed.gov/fulltext/EJ1126216.pdf

* 3.2 Increasing the level of inquiry [I, IN]

Grissom, A. N., Czajka, C. D., & McConnell, D. A. (2015). Revisions of Physical Geology Laboratory Courses to Increase the Level of Inquiry: Implications for Teaching and Learning. *Journal of Geoscience Education*, *63*(4), 285–296.

This paper describes a laboratory course revision process in introductory physical geology laboratory classes to increase the level of inquiry. The authors are from the department of Marine, Earth and Atmospheric Sciences, North Carolina State University, USA. A rubric (Buck et al., 2008) of inquiry levels (confirmation, structured, guided, open, authentic) was applied to classify activities. Classes containing a greater proportion of low-level inquiry activities were modified (e.g., reducing the number of samples students analyzed; replacing multiple fill-in-the-blank activities with fewer short-answer questions; having students first attempt to categorize a set of objects instead of following instructions; and exchanging directions about how to do something with challenges to achieve a goal). Teaching assistants were randomly assigned to teach either a traditional or revised version of the laboratory classes. Student performance was evaluated using multiple sources: (1) a pretest of conceptual knowledge (including questions from the Geoscience Concept Inventory (GCI; Libarkin and Anderson, 2005); (2) assessment exercises following each laboratory exercise; and (3) questions embedded in the mid-term and final exams. Learning gains were measured and compared between two rock and mineral laboratory classes (traditional n=153; revised n=207) and one geologic time class (traditional n=272; revised n=252). Activities with a modified inquiry level were found to positively influence student academic performance on post-laboratory assessments and related exam questions.

https://files.eric.ed.gov/fulltext/EJ1084587.pdf

3.3 Assessing inquiry in laboratory manuals [I, IN]

Ryker, K. D., & McConnell, D. A. (2017). Assessing Inquiry in Physical Geology Laboratory Manuals. *Journal of Geoscience Education*, *65*(1), 35–47.

This paper applies a measurement protocol to assess the level of inquiry present in four published physical geology laboratory manuals. The authors are from the Department of Geography and Geology, Eastern Michigan University and the Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, USA. Analysis shows the manuals incorporate mostly low-level inquiry activities (confirmation, structured). The same protocol was applied to the development of inquiry-based lessons for inclusion in a freshman-level physical geology laboratory course. Activities were adapted to increase inquiry levels demonstrating that it is possible to take publicly available resources and combine them with activities based around local geology. It is important to provide a mix of high- and low-inquiry activities. A table with sample activities for each laboratory topic at differing levels of inquiry is included. The authors conclude that while asking students to complete higher-level inquiry activities from the beginning of a laboratory may cause frustration, scaffolding learning to the point where students take on these activities can lead to a sense of accomplishment, improved theoretical understanding, and a view of science as a creative process.

https://files.eric.ed.gov/fulltext/EJ1135300.pdf

3.4 Developing scientific literacy [I, IN]

Surpless, B., Bushey, M., & Halx, M. (2014). Developing Scientific Literacy in Introductory Laboratory Courses: A Model for Course Design and Assessment. *Journal of Geoscience Education*, *62*(2), 244–263.

This is an example of a significant redesign for an introductory physical geology laboratory course based on research that demonstrates the efficacy of learning through active participation, interpretation, iteration, and reflection within an explicit scientific process context. In addition, new activities were added that involved the use of two new instruments to improve student understanding of qualitative and quantitative elemental analyses. A new course reader was developed that provided background materials for each activity and a new focus on the scientific process. Changes in student learning were assessed by multiple sources: in-class observations, student–instructor discussions, pre- and post-learning questionnaires, pre-laboratory quizzes, course activities completed during class time, modified post-activity reflection questions, practical examinations, and a final examination. Results (n=170) imply improved understanding of the scientific process and the nature of science; improved understanding of qualitative and quantitative elemental research methods; and improved understanding of the applicability of scientific research to real-world problems. Recommendations are included on how to transfer the curriculum development model to other geosciences departments and science disciplines.

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.477.2979&rep=rep1&type=pdf

3.5 Using Augmented Reality [U, IN]

Woods, T. L., Reed, S., Hsi, S., Woods, J. A., & Woods, M. R. (2016). Pilot Study Using the Augmented Reality Sandbox to Teach Topographic Maps and Surficial Processes in Introductory Geology Labs. *Journal of Education, 64*(3), 199–214.

A pilot study using the Augmented Reality sandbox (AR sandbox) suggests it can be a powerful tool for bridging the gap between two-dimensional (2D) representations and real landscapes, as well as enhancing the spatial thinking and modeling abilities of students. The authors are from the Department of Geological Sciences, East Carolina University, USA. The AR sandbox was used in undergraduate, physical geology courses to teach topographic maps and surficial features and processes. A typical lab syllabus is compared with one that includes the Sandbox exercises. In the latter, students engaged in model building of coastal and fluvial environments using a virtual water flow model to illustrate water flow dynamics on surface features. With the AR sandbox connected to a computer monitor, students could simultaneously see 3D landscapes in the sandbox and their corresponding 2D images on the monitor. Students used camera phones to capture landscape models they built and submitted them via e-mail for grading. Exit surveys (*n*=10) indicated students were overwhelmingly positive (97%) in their perception of how the AR sandbox improved their understanding of learning objectives. They also preferred AR sandbox activities when compared to traditional laboratories that used only topographic maps.

https://files.eric.ed.gov/fulltext/EJ1111551.pdf

4 Geography [U, IN]

4.1 Teaching computer programming skills with multiple laboratories [U, IN]

Etherington, T. R. (2016). Teaching introductory GIS programming to geographers using an open source Python approach. *Journal of Geography in Higher Education*, *40*(1), 117–130.

This paper outlines a Masters level geographic information system (GIS) course structured around a series of laboratories that teach introductory computer programming skills. The author is from the Institute for Applied Ecology New Zealand, School of Applied Sciences, Auckland University of Technology, New Zealand. Six laboratory exercises focusing on core spatial concepts of location, event, neighbourhood, field, object and network (Kuhn, 2012) were designed to teach Python (Open source, Version 2.7). Three methods of assessment are recommended to build confidence in the ability to program: self-assessment quizzes, self and peer laboratory assessments, and reflective writing. Feedback from students (*n*=29) at four universities was acquired from standardised university course reviews that asked general questions about positive and negative aspects of course design, teaching activities and assessment tasks. The voluntary and anonymous nature of the feedback precludes any contextualisation of comments, but students recognised the potential that Python GIS programming gives and this suggests greater emphasis on this aspect of a geographer's education is to be encouraged. The laboratory teaching materials developed and reported are available as supplementary material.

https://www.tandfonline.com/doi/abs/10.1080/03098265.2015.1086981

4.2 Outdoor laboratory [U, LC]

Oliver, C., Leader, S., & Kettridge, N. (2018). Birmingham Bog outdoor laboratory: potentials and possibilities for embedding field-based teaching within the undergraduate classroom. *Journal of Geography in Higher Education*, *42*(3), 442–459.

This paper assesses the potential of campus-based fieldwork to bridge the gap between lecture-based teaching and active learning. The authors are from the School of Geography, Earth and Environmental Sciences, University of Birmingham, UK. Developed principally for research, the Birmingham Bog (BB) is a designated space that consists of 12 mesocosms. It is integrated as a campus-based field site within a 3rd year undergraduate "Wetlands Environment" module that also includes lecture-style teaching to provide a theoretical basis and computer classes to aid in numerical analysis and modelling of core system processes. Located five minutes walk away from the lecture room, the BB removes students from the classroom, engages them with the theories they are being taught in the lecture, and allows them to assess their understanding through practical tasks. Evaluation of the extent to which the approach can complement or replace current field based teaching activities was explored through in-depth group interviews (2-5 students in each group comprising a representative sample of 25% of the class). Analysis suggests the BB was considered an example of "effective learning", however, the value placed on residential field courses cannot be met by such campus experiences. Despite this, an outdoor laboratory represents an increasingly fertile space for deeper stimulation and innovative ways of learning.

https://www.tandfonline.com/doi/abs/10.1080/03098265.2018.1455816

4.3 Playful mapping in interdisciplinary field course [U, IN]

Panek, J., & Perkins, C. (2018). Flying a kite: Playful mapping in a multidisciplinary field course. *Journal of Geography Higher Education*, *42*(3), 317–336.

Building upon published work about the potential of the technique, this article explores the possibilities of implementing kite-mapping during an interdisciplinary field course. The authors are from the Department of Development and Environmental Studies and the Department of Geoinformatics, Palacký University, and the Department of Computer Science and Applied Mathematics, Moravian University College, Olomouc, Czech Republic; and the School of Environment, Education and Development, University of Manchester, U.K. Kite-mapping is situated as a low cost, high quality, participatory approach, in relation to field use of maps. Practical issues in making the mapping work in two day-long workshops on the Maltese island of Gozo are described in three phases: building the mapping kit, mapping in the field, and data post-processing. A multi-method evaluation of staff and student reactions and experiences were used to explore the pedagogic aspects of kite mapping. Results (both strengths and weaknesses) suggest that the practices of kite mapping significantly impact upon the value of the mapping technique. Creative and playful mapping processes implicit in the technique might be usefully deployed in other field contexts.

https://www.tandfonline.com/doi/abs/10.1080/03098265.2018.1463975

4.4 Spiral curriculum and scaffolding for cartography [U, IN]

Sack, C. M., & Roth, R. E. (2017). Design and evaluation of an Open Web Platform cartography lab curriculum. *Journal of Geography Higher Education*, *41*(1), 1–23.

This paper describes the design and evaluation of a novel curriculum for the laboratory component of a web mapping course. The authors are from the Department of Geography at the University of Wisconsin-Madison, USA. Through experimentation, they recognized the need to shift attention from *what* to teach, i.e., Open Web Platform mapping tools (Leaflet and D3), to *how* to teach, i.e., key stumbling blocks for comprehension. A spiral curriculum (revisiting key concepts throughout the curriculum to reinforce them until students achieve mastery) is integrated with scaffolding (breaking the task down into highly structured and simplified steps followed by progressively less structure and assistance). Success of the new curriculum was evaluated (n=24) through triangulation between quantitative and qualitative data: an instructor observation log, student feedback compositions, and an exit survey. Results revealed significant growth in student abilities and confidence. This research provides a methodology for designing and evaluating curriculum around highly technical skills that are increasingly in demand in research, education, and industry careers and continuously in need of adaptation to ongoing technology trends.

https://www.tandfonline.com/doi/abs/10.1080/03098265.2016.1241987

* 4.5 Inquiry-based landscaped drawing [U, IN]

Tillmann, V. A., & Wunderlich, J. (2017). Dewey’s concept of experience for inquiry-based landscape drawing during field studies. *Journal of Geography Higher Education*, *41*(3), 383–402.

In this example, the philosophy of John Dewey is used as a theoretical basis to analyze processes of knowledge construction during geographical field studies. The authors are from the Department of Human Geography, Institute of Physical Geography, and eLearning Center at Geothe-University Frankfurt, Germany. Trainee teachers at the end of their second year participated in a compulsory three-day fieldtrip with a strong emphasis on physical geography. The act of drawing a perceived landscape was introduced to stimulate students to develop their own hypotheses on the landscape development of an unknown area, and to reflect on individual drawings in a group discussion. The aim was to foster the self-organized acquisition of relevant skills to explore, describe and reflect on subjective mental and linguistic concepts in relation to scientific landscape models. Evaluation data was collected during four consecutive years and comprised students' drawings, responses to questionnaires (intrinsic motivation, n=*93* and experience of flow, n=*91*) and a review of students' reflective notes. Results indicate that students were motivated to learn about the processes which formed the landscape and that they perceived the method of inquiry after Dewey positively. The approach presented serves not only to transfer knowledge about geomorphological processes but also to broaden views about knowledge acquisition and development.

https://www.tandfonline.com/doi/abs/10.1080/03098265.2017.1331206

5 Physics

* 5.1 Student ownership of projects [U, IN]

Dounas-Frazer, D. R., Stanley, J. T., & Lewandowski, H. J. (2017). Student ownership of projects in an upper-division optics laboratory course: A multiple case study of successful experiences. *Physical Review Physics Education Research, 13*.

Using a multiple case study approach, this study investigated students' sense of ownership of final projects in an upper-division optics lab course. The authors are from the Department of Physics, University of Colorado Boulder, and the National Institute of Standards and Technology and University of Colorado Boulder, USA. Within-case analyses focused on identifying and constructing chronological descriptions of key issues in each project. Cross-case analysis focused on identifying emergent themes with respect to project ownership relating to: student agency, instructor mentorship, peer collaboration, interest and value, and affective responses. Analysis yielded three major findings. First, coupling division of labor with collective brainstorming can help balance student agency, instructor mentorship, and peer collaboration. Second, students' interest in the project and perceptions of its value can increase over time; initial student interest in the project topic is not a necessary condition for student ownership of the project. Third, student ownership is characterized by a wide range of emotions that fluctuate as students alternate between extended periods of struggle and moments of success while working on their projects. These findings have concrete implications for the design of experimental physics projects for which student ownership is a desired learning outcome. The course and projects are described in sufficient detail that others can adapt the results to their particular contexts.

https://journals.aps.org/prper/pdf/10.1103/PhysRevPhysEducRes.13.020136

5.2 The efficacy of instructional labs [I, IN]

Holmes, N. G., Olsen, J., Thomas, J. L., & Weiman, C. E. (2017). Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content. *Physical Review Physics Education Research, 13*.

This multi-institution study measured the effectiveness of introductory lab courses on teaching scientific content. The authors are from Departments of Physics at Cornell University, University of Washington, and Stanford University and the Department of Physics and Astronomy at the University of New Mexico. Although encompassing a broad range of student populations and instructional styles, the nine courses studied had two key things in common: the labs aimed to reinforce the content presented in lectures, and the labs were optional. Performance was compared between students who did and did not take the labs (with careful normalization for selection effects). Results show universally and precisely no added value to learning course content from taking the labs as measured by course exam performance. One explanation for this result is that the lab activities were dominated by following instructions and specified procedures. Although physics concepts were central to the thinking of the instructor they got little attention from the student carrying out the assigned activities. Alternative goals and instructional approaches that would make lab courses more educationally valuable include: open-ended activities; providing students with time, opportunity, and incentive to revise, troubleshoot, or explore; and shifting the emphasis of activities towards the quality of students' process rather than the product they obtain.

https://arxiv.org/abs/1705.03580

5.3 Impact of reflective writing and labatorials (I, IN)

Kalman, C. S., Lattery, M., & Sobhanzadeh, M. (2018). Impact of Reflective Writing and Labatorials on Student Understanding of Force and Motion in Introductory Physics. *Creative Education*, *9*, 575–596.

In this study, reflective writing in combination with a new style of introductory physics labs called "labatorials" was used to investigate how students learn the concepts of force and motion. The authors are Physics professors from Concordia University in Montreal and Royal Mount University in Calgary, Canada, and the University of Wisconsin in Oskosh, USA. The reflective writing assignments involved students being prompted to write about what they were learning before coming to the classroom and on a weekly basis. "Labatorials" are a mix of laboratory work and tutorials. In small groups, students used a worksheet with conceptual questions, calculation problems, and instructions for experiments and computer simulations. Students were asked to make predictions about the conceptual questions and after doing the experiment to explain whether their results supported their prediction. Data (n=7) comprised analysis of pre- post-interviews (questions included in Appendix A) and students' written assignments (rubric included in Appendix B). Analysis suggests that students significantly increased their knowledge of Newton's theory of force when exposed to these two interventions. Students interviewed at the end of the semester discussed the relationship between force and motion in detail and used other physics concepts such as acceleration and Newton's laws to support their explanations. Consistency of the interviewees with the class in general was established by analysis of written assignments of a random selection of non-interviewed students (n=12) who gave permission to use their products in this study.

https://spectrum.library.concordia.ca/983780/1/Kalman-CE-2018.pdf

5.4 Team learning assessment [I, LC]

Leung, A. C. K., Hashemi Pour, B., Reynolds, D., & Jerzak, S. (2017). New Assessment Process in an Introductory Undergraduate Physics Laboratory: An Exploration on Collaborative Learning. *Assessment & Evaluation in Higher Education*, *42*(2), 169–181.

This example describes a new team learning assessment process designed and tested in two first-year university physics laboratory courses (n=287). The authors are from the Department of Physics and Astronomy, York University, Toronto, Canada. The assessment process provided a strong incentive for students to cooperate and feel responsible for each other's learning and fostered a sense of collaboration rather than competition. Specifically, students were randomly divided into teams of four to work on a physics experiment and, at the end of the session, only one team member was randomly selected to carry out a post-laboratory performance task. Results indicate that learning outcomes were not compromised and that peer instruction was employed to a greater extent compared to standard practice. Student responses from a post-assessment survey revealed that 76% of students considered the new assessment process to be fair, whereas 57% of students felt the standard process was fair. The new assessment process used in this study led to a 75% reduction in grading duties – an advantage for large classes.

https://www.tandfonline.com/doi/abs/10.1080/02602938.2015.1089977

5.5 Experimental design laboratories [I, IN]

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Parreira, P., & Yao, E. (2018). Experimental Design Laboratories in Introductory Physics Courses: Enhancing Cognitive Tasks and Deep Conceptual Learning. *Physics Education*, *53*(5).

This example presents an alternative to the regular introductory level physics laboratory experiments. The authors are professors at the School of Physics and Astronomy, University of Glasgow, U.K. The experimental design lab consists of two main sessions: familiarization with the equipment and planning, and dealing with the experimental challenge itself. Students are instructed to discuss in small groups all stages of their experimental challenge. The example provided involves building a data-logger with an Arduino. Students (*n*=280) were divided in groups of five and asked to submit their feedback to two open-ended questions in groups together with the lab report. The feedback received was voluntary and represented 93% of the class. Analysis with frequency data is summarized. Results suggest that student perception regarding the alternative labs is very positive. The authors say this may explain their overall better performance when compared to regular labs (data on student performance not included).

https://iopscience.iop.org/article/10.1088/1361-6552/aacf23/pdf

6 Psychology

6.1 A new model for teaching Intro Psych [I, LC]

Gurung, R. A. R., Enns, C., Cacioppo, J. T., Hackathorn, J., Frantz, S., Loop, T., & Freeman, J. E. (2016). Strengthening Introductory Psychology: A new model for teaching the introductory course. *American Psychologist*, *71*(2), 112–124.

This article proposes a new model to guide content coverage for teaching introductory psychology that also includes experiential or laboratory components. The authors represent a working group appointed by the APA's Board of Educational Affairs from 5 different higher education institutions in the USA. They advocate for greater commonality and assessment given the importance of the Intro Psych course (13,000 instructors teach the course in US colleges and universities with an estimated 1.2 to 1.6 million students). They propose that the content integrates a) scientific foundations, b) 5 major domains of knowledge, and c) cross-cutting themes relevant to all domains. Suggestions are provided for the laboratory components, e.g., a two-class period multidimensional scaling activity (McConnell & Marton, 2013) and lab software projects that allow for virtual experiments using the APA Online Psychology Lab, a free resource available for instructors and their students (http://opl.apa.org/). They further advocate for textbook publishers to use the model, national assessment standards and guidelines as well as training resources for instructors. The authors claim the model has considerable flexibility and allows for academic freedom.

https://psycnet.apa.org/fulltext/2016-06476-003.pdf

* 6.2 A new media-based lab to teach research methods [I, IN]

Hatch, D. L., Zschau, T., Hays, A., McAllister, K., Harrison, M., Cate, K. L., Shanks, R.A. & Lloyd, S. A. (2014). Of Mice and Meth: A New Media-Based Neuropsychopharmacology Lab to Teach Research Methods. *Teaching of Psychology*, *41*(2), 167–174.

This article describes an innovative neuropsychopharmacology laboratory that can be incorporated into any research methods class. All seven authors are from the Department of Psychological Science, University of North Georgia, USA. The lab consists of a set of interconnected modules centered on observations of methamphetamine-induced behavioral changes in mice. It was designed to simulate the traditional research process by providing students with a set of hands-on activities that guides them from an initial literature review to a final research report. To assess the practical utility of this new laboratory, an empirical study was conducted to compare the effectiveness of the live methods lab with an identical media-based lab. To replicate the observational component for the media-based treatment group, the mouse behaviors during the live lab were digitally recorded. Psychology students from two instructors' research methods courses (n=26 and n=27) participated in the study. Using a pretest–posttest design, participants completed the Student Assessment of Learning Gains (SALG) questionnaire. Results suggest that both the live and the media-based variations of this lab are similarly effective. To facilitate the adoption of the lab, all necessary materials are made available on a dedicated website.

https://journals.sagepub.com/doi/pdf/10.1177/0098628314530352

6.3 Comparing laboratories using live rats with a virtual rat [U, IN]

Hunt, M. J., & Macaskill, A. C. (2017). Student Responses to Active Learning Activities With Live and Virtual Rats in Psychology Teaching Laboratories. *Teaching of Psychology*, *44*(2), 160–164.

This article takes an ethical approach to using nonhuman animals in laboratory teaching compared to the benefits of alternative teaching practices. The authors are from the School of Psychology, Victoria University of Wellington, New Zealand. The study compared upper level undergraduate students' evaluations of psychology laboratories using live rats with their evaluations of using a virtual rat (Sniffy). Each student worked individually with Sniffy Pro Version 5 (Thomson Wadsworth) for about 90 mins. This lab was not graded but students could not pass the course if they were absent without a documented excuse. The rat labs occurred during the 2 weeks following the virtual-rat lab. Teams of approximately six students worked with one Norway hooded rat and completed six 1-hr sessions. Any student could opt out of working with a live rat and instead complete alternative coursework. An anonymous questionnaire was completed during the final lecture period. Students (n= 79) reported that the live-rat labs were ethically acceptable and that working with live rats enhanced their learning to a greater extent than working with Sniffy. These results support the retention of laboratories using live rats in psychology courses.

https://journals.sagepub.com/doi/pdf/10.1177/0098628317692632

6.4 Laboratory learning and cooperative learning [U, LC]

Knapp, S. (2016). Laboratory Learning in a Research Methods Course: Successes and Challenges. *SAGE Open Creative Commons*, 1–8. https://doi.org/10.1177/2158244016636180

This study sought to create an effective laboratory environment within a research methods course and to assess students' perceptions of this approach. The author is from Southern Vermont College, Bennington, USA. The course was cross-listed in the criminal justice, health care management and advocacy, and psychology majors. It involved students completing eight problem-based laboratory projects (details included) in small groups throughout the semester. Students completed a survey at the end of the semester for extra credit. Questions addressed their perceptions of the effectiveness of laboratory learning and cooperative learning, and their thoughts, feelings, and/or observations about working in small groups. Two studies (n=17 and n=20) are reported with improvements made from one semester to the next. Across both samples, students' responses to laboratory learning were generally positive. Overall, they benefitted from the opportunity to learn from, and to teach their peers. They also felt more comfortable contributing in small groups than speaking up in front of the entire class, and applying the concepts they were learning in class made them feel more competent with the course material. However, groups continued to struggle with social loafing and conflicting personalities among group members. Future research should address these concerns and assess objective student outcomes, such as course grades.

https://journals.sagepub.com/doi/pdf/10.1177/2158244016636180

6.5 A survey of research experiences in Intro Psych courses [I, IN]

Peterson, J. J., & Sesma, A. (2017). Introductory Psychology: What's Lab Got to Do With It? *Teaching of Psychology*, *44*(4), 313–323.

This study sampled a national, randomly selected pool of colleges and universities to provide a descriptive account of research experiences offered in introductory psychology courses, and to explore instructors' perceptions of and perceived barriers to integrating research. The authors are from St. Catherine University, St. Paul, Minnesota, USA. A total of 259 individuals completed the survey for an estimated response rate of 26%. Results show that although few of the introductory courses have a separate laboratory (5%), over 75% of the respondents indicated some manner of research activity in their courses. Most introductory courses included opportunities to read and critique original research, but few provided students with hands-on research, APA writing, or data presentation opportunities. Respondents also rated activities such as designing, conducting, and interpreting research as not especially important for introductory courses. Primary barriers to integrating research are logistical in nature. A promising avenue for future research is to examine potential moderating effects of students' achievement levels on the relation between research experiences in introductory psychology courses and student recruitment to or retention in a psychology major.

https://journals.sagepub.com/doi/pdf/10.1177/0098628317727643

7 Training Teaching Assistants

7.1 Evaluating a GTA program for laboratory teaching

Flaherty, A., O'Dwyer, A., Mannix-McNamara, P., & Leahy, J. J. (2017). Evaluating the Impact of the "Teaching as a Chemistry Laboratory Graduate Teaching Assistant" Program on Cognitive and Psychomotor Verbal Interactions in the Laboratory. *Journal of Chemical Education*, *94*(12), 1831–1843.

This article includes a summary of 4 laboratory instructional models and the methods by which they have been evaluated (Science Writing Heuristic, SE Learning Cycle, Predict-Observe-Explain, and Peer-led Teaching and Learning Techniques). The authors are professors at the National Centre for STEM Education, University of Limerick, Ireland. A new model, Meaningful Learning in the Laboratory (MLL), is proposed that guides GTA's conceptions about how students learn, and how to use these conceptions to inform instruction. The MLL focuses on the three domains of learning (what students *know*, the *skills* they experience, and how they *feel* about the laboratory experience). Impact was evaluated in terms of verbal interactions between GTAs and students. Data comprised transcriptions of audio recordings for participants (n=7) at three different stages as well as member checking with stakeholder groups. By the end of the program, interaction between GTAs and students in the laboratory increased and the extent of conceptual discussion between GTAs and students also increased.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.7b00370

* 7.2 Inquiry-based vs. "best practices" GTA training

Hughes, P. W., & Ellefson, M. R. (2013). Inquiry-based training improves teaching effectiveness of biology teaching assistants. *PLOS ONE*, *8*(9). https://doi.org/doi:10.1371/journal.pone.0078540

This large study investigated whether grounding GTA training in inquiry-based learning theory would improve teaching performance in undergraduate biology labs. The authors are from the Department of Biology, Carleton University, Ottawa, Canada, and the Faculty of Education, University of Cambridge, U.K. A semi-randomized trial was conducted to compare two training regimens: one that was taught "best practices" associated with lab teaching (control), and one that explained inquiry-oriented pedagogy (experimental). Seminar activities for both groups are included. Teaching effectiveness for volunteer GTAs (*n*=54) was assessed by undergraduate students (*n*=352) using three measures: (a) the student evaluation of educational quality (SEEQ) questionnaire; (b) a cognitive learning evaluation (CLE) questionnaire; and (c) standardized mean student grade. GTAs who completed the inquiry pedagogy training were rated as better organized, provided better feedback on assignments, and were better overall teachers of both higher- and lower-order skills than GTAs in the control training. GTAs who completed the inquiry-based training also reported significantly higher standardized grades than those in the control training. The results indicate that GTAs are better able to teach undergraduates to "reason like scientists" after inquiry-based learning pedagogy training, even when training is limited to only five hours.

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0078540

7.3 How to fully benefit from GTAs

Ryan, B. J. (2014). Graduate Teaching Assistants; Critical Colleagues or Casual Components in the Undergraduate Laboratory Learning? An Exploration of the Role of the Postgraduate Teacher in the Sciences. *European Journal of Science and Mathematics Education*, *2*(2), 98–105.

This article reviews graduate teaching assistant (GTA) training in Europe specifically in the context of a structured PhD programme. The author is from the College of Sciences and Health, Dublin Institute of Technology, Ireland. He argues that when the style of a laboratory is to promote the skills of the research scientist (rather than an expository style lab) then the GTA is critical to laboratory teaching. He concludes with seven recommendations for practice: provide correct training before the GTA teaches and support during their teaching duties; foster a community of practice among GTAs; couple minimal curriculum change with appropriate GTA training in inquiry based learning; inform students of third level education expectations, their role in their learning and involve them in laboratory design; encourage fluid and 'peer'-like interaction between the GTA and the undergraduate; and include GTAs in the development of the laboratories and the teaching community. To fully benefit from GTAs, they must be equipped with the skills required to enhance the learning experience of undergraduates, teach in a stimulating and research orientated environment, and be supported by their mentoring academic and institute.

https://arrow.dit.ie/cgi/viewcontent.cgi?article=1170&context=schfsehart

7.4 Can undergraduate TAs be used in lieu of graduate TAs?

Wheeler, L. B., Maeng, J. L., Chiu, J. L., & Bell, R. L. (2017). Do Teaching Assistants Matter? Investigating Relationships between Teaching Assistants and Student Outcomes in Undergraduate Science Laboratory Classes. *Journal of Research in Science Teaching*, *54*(4), 463–492.

This quantitative study examined (i) the impact of inquiry-based TA professional development (PD) on TAs' content knowledge, beliefs, and confidence; (ii) the use of UTAs in parallel roles to GTAs in inquiry-based laboratories; and (iii) the relationship between TAs content knowledge and student learning outcomes in an inquiry-based general chemistry laboratory context. The authors are from the University of Virginia, Charlottesville, and Oregan State University, Corvallis. PD supported TAs to lead inquiry-based classes, involving a weeklong workshop and 14 weekly follow-up meetings. Participants included 5 UTAs, 14 GTAs, and their 529 students. Results demonstrate that TAs' content knowledge improved following PD and teaching, and students' content knowledge significantly improved across the semester. Further, TAs with higher content knowledge post-PD tended to have students with higher end-of-semester content knowledge. No differences existed between UTAs or GTAs on any TA characteristic or student outcome measure. Student demographics were significant predictors of student post-survey content scores and students' perceptions of their TA differed based on gender and international TA status.

https://onlinelibrary.wiley.com/doi/full/10.1002/tea.21373

7.5 Importance of TA training for inquiry-based laboratory course

Wheeler, L. B., Clark, C. P., & Grisham, C. M. (2017). Transforming a Traditional Laboratory to an Inquiry-Based Course: Importance of Training TAs When Redesigning a Curriculum. *Journal of Chemical Education*, *94*(8), 1019–1026.

This article describes an inquiry-based curriculum for a general chemistry laboratory and TA training program with a full list of components, activities and resources included. The authors are from the Department of Chemistry and Center for Teaching Excellence, University of Virginia, Charlottesville, USA. The training program covers teaching theory, pedagogy, and practical aspects of laboratory teaching thus allowing students to master chemical concepts while learning to think and act like scientists. The benefits of an immersive weeklong training process for both undergraduate TAs (UTAs) and graduate TAs (GTAs) are discussed. References to previous studies by the principal author are provided as evidence of efficacy (e.g., the previous example). Suggestions are offered on ways to implement a similar model in other university contexts: begin with pilot programs, do not reinvent the wheel, get your department on board, utilize students in the process of curriculum development, and seek help when needed from the institution's teaching resource center.

https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.6b00831

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