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<th>Author</th>
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<th>Teaching &amp; Learning Theory</th>
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<td>Abraham, M. R., Cracolice, M. S., Graves, A. P., Aladamash, A. H., Kihega, J. G., Palma Gil, J. G., et al.</td>
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<td>McCreary, C.L., Golde, M.F., Koeske, R.</td>
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<td>Mohrig, J.R., Hammond, C.N., Colby, D.A.</td>
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<td>Vosniadous, S, Ioannides C, Dimitrakopoulou A, Papademetriou, E.</td>
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<td>Yeary, M., et. al.</td>
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<td>Zumbach, J., et. al.</td>
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- Provides an overview of the state of chemistry laboratories (one decade ago). The statistic that only 26 percent of reporting educational institutions used computers for laboratory activities at that time shows how quickly and pervasively technological innovations have occurred.
- Notes importance of establishing laboratory goals. Results of their study demonstrate that the highest priority lab goal is concept comprehension.
- Distinguishes between inquiry laboratories and traditional laboratory formats on the basis of their treatment of the relationship of data and concepts. In inquiry labs, data may be used to introduce a concept (inductive approach), whereas traditional labs use data as a means of confirming concepts (deductive approach).


- Due to the smaller size of the laboratory compared to the lecture hall in large science courses, TAs frequently have more personal contact with students than the professors do. Hunter College used post-bacc, non graduate students as TAs, leading to higher student satisfaction than when graduate student TAs assisted with the laboratory experience.
- It is posited that this greater satisfaction resulted from the higher priority these students placed upon teaching; the post-bacc’s may also have had comparatively more time to prepare materials.


- Consider furnishing needs and service needs (water, gas, electric) in tandem when designing lab spaces.
- Echoes’ others emphasis regarding the importance of having a representative of the lab users who is also knowledgeable about architectural design to represent users’ needs to the architect.
- Provides information on fume hood specifications [n.b.: likely outdated]


- Presents positive educational ramifications of establishing remote and virtual laboratories: support for asynchronous student learning allows students to conduct experiments repeatedly and on their own time, thereby increasing student convenience and competency.
- This flexibility encourages students to take responsibility for their own learning.


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Teaching Labs in the University Setting:
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- Plan for obsolescence when preparing to build: realize that technologies are changing quickly and try to make spaces flexible for what future technology may be available.
- Ongoing clear communication needed with all parties involved, to avoid professional / political repercussions.
- Gives practical, basic advice regarding timelines and keeping the intended purpose(s) of the space at the forefront when making design decisions.

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- Importance of considering aesthetics in renovations
- Need to accommodate existing structures when renovating
- Recommends being aware of the likelihood of unanticipated complaints
- Suggests incorporating an understanding of the overall extent of the work involved when considering renovations.


- Expresses the need for a constructivist approach in graduate TA seminar courses that support their teaching efforts. Recognizes TA ability to transmit conceptions about laboratory learning and support students' understanding. Suggests that the semester-long TA training course is an integral step for success
- Defines constructivism as people's ability to garner meaning from and adapt to environmental conditions and circumstances.
- Provides examples of recommendations TAs are expected to follow and enforce within the laboratory environment.


- Notes that effective use of time is of particular concern in genetics laboratory settings, where specimen preparation is often quite time-consuming
- Details the use of Scenario-Based-Learning Interactive (SBLi) software in the creation of a virtual laboratory as a course supplement, resulting in savings of time, money, and mitigated safety concerns. Describes the SBLi software as being easily customizable to the needs of a given course.

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- Notes the prevalence of the word "inquiry" throughout education literature; suggests that disambiguation is needed between inquiry as a teaching style and inquiry as a research method.
- Lists "inquiry" modifiers, including guided-, structured-, partial-, authentic-, and directed-inquiry.(52)
- Provides example of evaluation rubric used by faculty to assess the extent to which their laboratory curriculum accommodates inquiry. [This is a very basic tool, but nonetheless

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- Recommends consulting numerous energy benchmarks available whether preparing for renovations or new building; provides examples regarding ventilation, cooling/heating and lighting
- Mentions Labs21 Benchmarking tools.


- Importance of recognizing the link between well-established, clear, supported objectives and resulting outcomes of the laboratory experience.
- Encourages academics to reflect upon curriculum decisions and lab design. Argues for faculty engagement at the level of “teaching and learning principles”, above the level of teaching behaviours.
- When pedagogy, instructional methods and teaching in the laboratory as supporting the affective environment are discussed, this provides an implicitly direct reflection upon the learning outcomes expected to result.


- Need to make links between laboratory and lecture more explicit.
- Recommended performing demonstrations or including presentation of specimens to better illustrate lectures.


- Describes process of adopting and adapting pre-existing game engine to enable students to conduct science laboratories via the computer.
- Stated benefits include the appeal to students with varied learning styles, use of a format that is familiar to many students, options for students to repeat experiments to enforce concepts and processes, and saving the university resources that would otherwise be required.
- Indicates that this could be used as a supplement or in lieu of traditional experiments.


- Learning is not a passive process; time is required to assimilate new concepts or clarifications of preexisting concepts into a working knowledge. This can be facilitated when students utilize their newly acquired knowledge in an unfamiliar situation.
Teaching Labs in the University Setting: Annotated Bibliography

- Realistic laboratory scenarios offer a higher likelihood that students will be able to apply their background information to the related challenges, which may result in students becoming aware of (and subsequently modifying) prior misconceptions.


- Presents an empirical research study comparing students’ performance and perceptions related to remote, hands-on and simulated labs. Lab test scores were highest for students who completed the lab remotely. The authors hasten to note that the lab teams in which students worked appeared to have a substantial effect upon this discrepancy, thus suggesting that lab group dynamics effect learning.
- Students completing remote and simulated labs conducted data collection individually, giving them more opportunities for practice.
- Students substantially preferred the remote lab when considering convenience, setup and time spent.
- Conclusion: a combination of independent and collaborative work may maximize student learning; authors recommend that the implementation of new laboratory technologies be accompanied by evaluation of the collaboration types that can best support it.


- Online discussion - pro: some students contributed more than in-class; con: discussions were often dominated by only a few students.
- Technology may facilitate new means of learning, but ultimately effective pedagogy and student engagement determine whether learning objectives are met or surpassed.
- Electronically - enabled learning was used to introduce students to material prior to laboratory period, thus maximizing course time.


- Posits that a combination of traditional and technology-advanced approaches can most effectively meet students’ learning needs. Suggests that technology should be seen as a tool to add to or otherwise enhance current practices, rather than replace them entirely.
- Notes that challenges associated with implementing computer-based tools (in this case, WebCT and related materials) included students’ exaggerated conceptions of their information technology capabilities and their substantially varied extent of prior experiences using computers.
- Students’ ability to repeat and practice with the interactive materials online leads to greater proficiency.

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- Describes interactive whiteboard and clicker technologies
Teaching Labs in the University Setting:
Annotated Bibliography

- Remember that technological tools are not ends, but rather means to supporting effective instruction.

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- Lists varied question formats used within computerized problem sets program.
- Prescribed problem sets effectively guide students’ studying and review of concepts.
- Convenience associated with electronic access and ability to repeat problem sets to solidify skills in both data collection and analysis.


- Very concise presentation of laboratory instruction styles, focusing upon expository, inquiry, discovery-based and problem-based instruction. Varying combinations of their outcomes, approaches and procedures distinguish these instruction styles from one another.
- Explains the hierarchy of Bloom’s Taxonomy.
- Designates expository instruction as both the most popular and most strongly critiqued style.


- Provides brief history of chemistry instruction, conceptions of the lab as a research space, and different mentoring models.
- Describes Cognitive Apprenticeship Theory within the situated learning paradigm, wherein the learning environment is described by considering the contents, methods, sequence and sociology comprising the information exchange parameters.
- Suggests that this holistic approach allows students to better understand scientific concepts from the viewpoint of participants in a research lab.

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- Addresses challenges associated with space, time, and budget relevant to modifying and integrating lab components into course practices.
- Notes proliferation of multimedia, interactive software, data acquisition and video supporting systems being used in laboratory settings for purposes of instruction and demonstration.
- Observes rising popularity of remotely accessible laboratories
- Enumerates step-by-step procedure that user would follow to access a given remotely accessible laboratory experiment. Explains software and supporting hardware requirements.

Teaching Labs in the University Setting: Annotated Bibliography

- As in other articles, this notes the proliferation of numerous interpretations of the term inquiry in the absence of an operational definition or controlled vocabulary, ultimately leading to inconsistent conceptions of what inquiry entails.
- Provides an overview of constructivism, inquiry and the purposes of the laboratory.


- Describes the use of Second Life as a tool to assist in distance education courses; many universities partner with the New Media Consortium in implementing a Second Life presence.
- Advantages: professors report livelier communication between students in a digital setting.
- Disadvantages: frequent technological issues with the Second Life program; challenges of moving virtual personae through the different Second Life regions.


- Presents teaching as a very effective method of learning content (i.e. must understand content to communicate it well).
- As a result, TAs benefit from teaching inquiry-based labs. Benefits include an improved ability to critique, interpret and evaluate experimental designs, discussions and problems.


- Introduces the iLab project and consortium at MIT.
- Distinguishes between hands-on labs and software toolkits: these are not to be considered equivalent; it is important to consider what medium will best support the concepts and skills to be taught within the lab.
- Inter-university adoption of the iLab approach continues, contributing to a collaborative network that has seen particular adoption in Australian universities.


- Acknowledges that traditional laboratory manual based instruction resulted from a lack of time, space, resources and faculty. Provides recommendations for successful teaching practices given these constraints, based upon surveys given to both TAs and students with Likert scale - styled statements describing the perceived importance of varied components of effective teaching.
- Table 3 provides a clear description of the survey results within the themes of knowledge, communication skills and affective domain, complete with sub-topics, examples and explanations of the benefits of the described behaviours to students.


- An update and reflection upon a review of the state of science laboratories published by the same authors ~20 years previously.

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- It notes the far-reaching outcomes of effective teaching, provides updates regarding the implementation of various learning models, and emphasizes the roles of student perception, the learning environment and learning styles in the laboratory setting.
- Encourages ongoing professional development
- States the need for consistency between desired learning outcomes and chosen assessment methods.

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- Lists integral details for providing a thorough description in articles of research done in the scientific field, particularly when this takes place within the laboratory setting (i.e. describing results of case studies).
- The details listed are also relevant and worthy of consideration when preparing to teach a course or its corresponding laboratory.

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- Four major points to consider when scientists collaborate with architects to plan laboratory spaces: (1) design for change (2) consider lab operational technology (3) health threats (4) need for humane environment (lighting, furniture etc.)
- Explains concept of designing on a modular basis to preserve functional space units regardless of future changes.
- Emphasizes importance of visiting other spaces the architect has designed before making a choice: does their design style and knowledge of the needs of laboratory spaces coincide with what your department / institution requires?

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- Breaks down inquiry-based instruction methods into subcategories: bounded inquiry, replicate inquiry and rolling inquiry, indicating some (dis)advantages of each.
- Provides recommendations for capitalizing on necessarily large class sizes in introductory courses by compiling the larger resulting data sets to form the basis of more significant analysis and meaningful results.
- Describes databases and spreadsheets used to facilitate data entry, analysis and transfer.

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- Need for student-professor collaboration in assessment; in its absence other collaboration does not proceed as smoothly.
- Students create concept maps demonstrating their understanding of laboratory content as one means of both formative and summative assessment.
- Discussion surrounding formation and revision of concept maps led to more productive communication between students, their peers and the instructor.

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- [GIS = Geographic Information Systems]
- A student's ability to use technology does not assume the comprehension of the underlying processes occurring, or why a certain answer results.
- Students should come to understand the process by which one arrives at an electronically produced result. [This is analogous to teaching students how to do basic computation before introducing calculators, thus allowing them to have a background knowledge from which to evaluate the validity of their result.]

[Access: McGill subscription – Education]
- Compares tendencies of full-time vs. adjunct professors: the former were more likely to emphasize class discussion and student participation, and to use slides (often PowerPoint) to supplement their lectures.
- Acknowledges time-consuming aspect of laboratory preparation and instruction.
- To instruct students effectively, it is necessary to understand how they learn best. Recommends assessing students' preferred learning styles, and using this assessment to inform the ways in which lectures and laboratory activities are presented, including appropriate tools.

- Considers the particular reasons that a given institution may want to build sustainably when designing new laboratory buildings – environmentally conscious, politics, good marketing, etc.
- Presents many parameters, ranging from ventilation to lighting and window glazing type, with helpful table summarization of relevant guidelines, building codes, practices & targets for design.

[Access: www.mcgill.ca/library → article indexes & databases → education → core databases → Education Full Text (Wilson) → enter title in search box.]
- Horizons for internet technology as both a primary and supplementary means of instruction
- Concept of action research: involves intentional reflection by the professor upon his/her methodological and pedagogical practices

[Access: www.mcgill.ca/library → article indexes & databases → education → core databases → Education Full Text (Wilson) → enter title in search box.]
- Clearly explains the use of Silicon Chalk® and Graphire® Tablet, two tools for networking and interfacing leading to the sharing of collected data and the uploading of handwritten graphs, diagrams etc. into word processing software, respectively.
- Details pros and cons of the above, including student feedback.

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- [N.B. - writer bias; conclusions drawn from student feedback statistics provided are not wholly objective.]


- Labs instructed by undergraduate mentors ("Undergraduates Teaching Undergraduates, or UTUs), group sizes are modified to allow for increased communication time with the mentor.
- Expresses the need for nurturing high-level thinking skills with direct relevance to the scientific method, which can then be applied across courses. These skills include awareness of the experiment’s organizational structure, assessing and explaining the quality of an observation or result, and extending skills and knowledge gained in the lab to other scenarios. The authors argue that these four skills provide a framework for learning.


- Explains mini-projects concept as a means of increasing students’ independence and intrinsic motivation for projects.
- Includes a helpful flow chart demonstrating the steps involved in developing mini-projects, which include (among others) establishing a project plan, implementing risk assessment, gathering and analyzing data, and presenting findings.
- Authors observed benefits including increased participation, morale and engagement as a result of implementing the mini-projects approach to laboratory work.


- Focuses upon inquiry based experiments, distinguishing between guided inquiry, design-based experiments and open-ended inquiry.
- Provides examples of how to modify verification-type ("traditional") experiments into inquiry-based experiments, thereby leading to increased student engagement.
- Expresses need for TAs to understand purposes and rationale supporting inquiry methods, if the professor chooses to implement this style of laboratory. Explains benefits that TAs saw for their own research while providing instruction supporting inquiry-driven experiments.
- Notes importance of dedicating time to pre- and post-discussion of laboratory / results.


- Describes virtual laboratory experiment undertaken, including perceptions of its success. Notes savings of time, flexibility, and alleviation of need for equipment access.
- Notes challenges of scheduling traditional laboratories; suggests that virtual laboratories may be a [partial] alternative.


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- Use of computers / multimedia to implement principles of Bloom's Taxonomy in the laboratory
- Suggests that the use of virtual reality interfaces improves access to previously inaccessible environments and maximizes in-class time use.
- [N.B. - inconsistent statistics re. student preferences for traditional lecture / interactive learning.]

[Access: www.sciencedirect.com and enter title in title search field]

- Acknowledges dissenting opinions among educators regarding what technologies should be used within the laboratory. Considers this discourse valid, observing that changes in laboratory technologies can lead to changes in both the economics and effectiveness of education.
- Questions the extent to which asynchronous communication can result in outcomes as effectively as real-time communication.
- Benefits of hands-on laboratories: unanticipated results force students to react and consider alternatives or explanations.
- Benefits of simulations: can be less expensive than hands-on labs, when preparation time is factored in.
- Benefits of remotely operated labs: relatively inexpensive, use real data, don't require as much space as hands-on labs.
- Brings up the point of a sense of physical and social presence as having impacts upon educational efficacy of the lab experience; to what extent are these modified or eliminated within a remote or simulated laboratory format?


- Explored impacts of TAs on undergraduate students' decision whether or not to major in science.
- TAs have a significant effect… upon students' perceptions of science, the lab climate (supportive or stressful), and students' understanding of future career options in the science field.
- Suggests that TA training programs should discuss lab climate, effective implementation of student group work, and classroom management / addressing interpersonal issues between students.


- When establishing objectives, the professor should consider not only what he/she intends to achieve with the laboratory work, but also how the students perceive the laboratory work and their comprehension of the objectives.
- Outlines the authors' conceptions of the purposes of lab work in scientific education, including:
  - Acquire conceptual and theoretical knowledge (leads to improved understanding of science)
  - Carry out scientific work using the inquiry process, developing practical skills
  - Lead to an increased interest in science

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- Perhaps above all, this book illustrates the point that modernity is relative. 
- Although it acknowledges the need for spaces to be able to evolve and change to reflect up-to-date knowledge and support current research methods, the spaces pictured would not be able to do so successfully within today’s laboratory environment. 
- The organization of the book encourages a thorough consideration of the many aspects involved in designing laboratory and support spaces; although their subsidiary content may be outdated, the aspects themselves are still relevant.


- Describes a course that commences with traditional “cookbook” laboratories and gradually moves to less prescribed labs, thereby scaffolding students’ learning experience. 
- Recommends that students maintain laboratory notebooks, to be handed in at the close of each laboratory period. 
- Reports overall positive feedback from students regarding the course structure and resulting laboratory experiments. 
- Details expectations for students’ final products following the conclusion of the lab.


- Presents findings regarding team collaboration: states that team size significantly effects team functioning (or lack thereof). Teams of 3 students are considered ideal for investigative laboratory work; teams of 4+ students generally lead to uneven workload distribution. 
- Recommends establishing team norms or contracts for long-term group work. 
- Suggests student teams have lab notebook requirement as means of accountability 
- Better collaborative teamwork leads to better scientific results in the lab. 
- Cites basic elements of cooperative learning groups (skills apply across disciplines) promoted by effective teams.


- Describes integration of modeling software and database instruction and use in the biology laboratory setting (including a NIH database), following science librarian's lecture. 
- Enables communication of results of high-level research and three-dimensional structures within the constraints of an undergraduate laboratory. 
- Emphasizes the importance of research - to - lab connections for students.


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- Describes use of Video Imaging Equipment (VIE) within the laboratory setting; considered preferable to PowerPoint.
- Students used VIE to efficiently show and describe structures to the instructor, improving student engagement, making the lab more interactive, and increasing communication.

[Access: www.mcgill.ca/library → article indexes & databases → education → core databases → Education Full Text (Wilson) → enter title in search box.]

- Encourages professors to move from "cookbook" labs to problem-based, inquiry and cooperative learning, citing prior literature with a similar viewpoint.
- Details inquiry process as applied to a laboratory on soil microbes
- Outcomes included students developing their own queries, hypotheses, and giving a conference-style presentation of their work and findings to their classmates.

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- Provides a helpful perspective on balancing the functional and aesthetic needs of lab spaces, with regards to considering how users will interact with them and how a space represents an institution.
- Stunning photography of a variety of types of labs
- The laboratory space should have a mission / objective(s) of its own, which are consistent with and support those of the course and department. Design decisions should be made with this in mind.


- Addresses various considerations relevant to renovating current laboratories, constructing new laboratories, and constructing entirely new buildings.
- Encourages scientists to work continually with architects in planning meetings throughout design and construction process.
- Expresses need for scientists to "balance client administration and faculty needs with objective oversight of practice-side design features, constraints, and capacity for innovative uses with new curricula" (p. 241)
- Table 1 effectively summarizes many of the points put forth by this article.


- Chose to move away from lab manual approach, and allowed students to choose their particular experimental topics, within a framework. Students completed an authentic laboratory experience: crafting a proposal, conducting research, experiment development and establishment of lab procedures, gathering/obtaining supplies, and finally carrying out and teaching their classmates the lab.
- The authors report that this approach led to improved attendance, overall positive attitudes, increased engagement, and consistently strong presentations. Students reported enjoying the overall experience, and learning the most when preparing to teach their own lab.

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- Suggests that this approach is akin to that conducted by upper-level science researchers.


[Access: www.sciencedirect.com and enter title in title search field]

- Learning occurs effectively in environments that facilitate group work, communication, and allow students to interact, explore and compare their conceptions with the conceptions of their peers.
- Vygotsky's Zone of Proximal Development
- Constructivism – emphasizes the importance of encouraging collaboration and introducing meaningful activities from which students can extrapolate their understanding.


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- Numerous studies note that the incorporation of (visual) multimedia in instruction particularly contributes to an involved learning environment and improved attitudes towards challenging intellectual ideas, among other benefits.
- In addition, multimedia usage is adaptable to multiple learning styles.
- However, also notes that not all studies find significant differences in students' benefit between classes incorporating multimedia and more "traditional" classes; recommends further research.
- Benefits of virtual laboratory experiments include the ability to manipulate the image on the screen and receive immediate feedback from the program's resulting calculations.


[May have to click "full text" tool on right-hand side of screen to view article]

- Suggests using collaborative learning to engage students and promote increased discussion and problem solving capabilities. Notes benefits of peer-to-peer instruction.
- Notes lack of consistently stated objectives of the laboratory experience across institutions.
- [N.B. – First couple of paragraphs effectively connect a number of the issues we have been addressing.]

Yeary, M., et. al. (2007). A hands-on, interdisciplinary laboratory program and educational model to strengthen a radar curriculum for broad distribution. *Advances in Engineering Education*, 1(1).

- Goal of program is to develop a cross-science interdisciplinary community of university scholars with active student participants and peer teachers.
- It is important that there be no gap between teaching and research; encourages faculty to combine the two.
- Created and integrated modules regarding various aspects of data collection and analysis across courses to emphasize idea that the concepts presented therein go beyond the scope of a given course.


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- "Out-of-context learning often leads to students being unable to apply their knowledge" (283)
- Suggests virtual science labs and computer-based learning environments as potential solutions for universities that cannot provide an equivalent physical setting or laboratory tools.
- Outlines LifeLab® project (currently used in Germany, English version in development)
- Learners with more initial knowledge often tend to benefit more from simulation-based learning; suggests that professors consider equitable benefits and how best to communicate course content to all students.