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Vicky F. Rands, Suzanne Hood, Ron Gerrits, and Murray Jensen

Corresponding Author: Vicky.Rands@slcc.edu

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Vicky F. Rands, PhD[1], Suzanne Hood, PhD[2], Ron Gerrits, PhD[3], Murray Jensen, PhD[4]
[1]Salt Lake Community College, 3491 W. Wights Fort Rd., West Jordan, UT Vicky.Rands@slcc.edu
[2]Department of Psychology, Bishop's University, 2600 College St., Sherbrooke, QC shood@ubishops.ca
[3]Milwaukee School of Engineering, 1025 North Broadway, Milwaukee, WI gerrits@msoe.edu
[4]School of Biological Sciences, University of Minnesota, 420 Washington Ave SE Minneapolis, MN msjensen@umn.edu

Abstract
Guided inquiry is an active learning technique featuring collaborative group learning with a structured set of models and highly structured questions for students to discuss and answer. Moving this technique to an online delivery format presents challenges, leading to questions about the effectiveness of this technique during online instruction. This study looked at the synchronous online delivery of a sliding filament theory guided inquiry activity (Brown 2015) and scores on related exam questions in anatomy classes at Salt Lake Community College. Students who participated in the guided inquiry activity had a median score of 79% on questions related to the sliding filament theory of muscle contraction while those that did not participate in guided inquiry had a median score of 61%, revealing a medium effect on student test scores. This suggests that the guided inquiry activity was successful at improving student understanding and retention when delivered in the online teaching environment.
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Key words: guided inquiry, sliding filament, anatomy, muscle contraction, active learning

Introduction

Active learning techniques have been embraced by many STEM (Science, Technology, Engineering, Math) instructors to foster student learning. A meta-analysis performed by Freeman and coworkers in 2014 demonstrated that students are 1.5 times more likely to fail a STEM lecture-formatted class compared to a STEM class using active learning techniques (Freeman et al. 2014). The beneficial effects of active learning in biology courses were also found to be consistent with a failure reduction (Beck et al. 2014). They found that students performed 0.73 standard deviations (SD) better in biology laboratory courses with active learning than did students in a standard laboratory course (Beck et al. 2014). These positive outcomes may be related to the fact that active learning is especially beneficial for complex concepts such as those presented in biology and its subdisciplines such as anatomy and physiology (Jensen and Lawson 2011).

Guided inquiry is an active learning technique that features collaborative group learning with a structured set of models and questions for students to discuss and answer. A recent meta-analysis of 87 guided inquiry studies covering many educational subjects, including anatomy and physiology, demonstrated a positive impact on students' content knowledge and the number of students earning A grades (Rodriguez et al. 2020). First adapted for chemistry Instruction (Farrell et al. 1999), guided inquiry has proven to be an excellent fit for biology courses (Armbruster et al. 2009). Guided inquiry springs from constructivist learning pedagogy founded on the principle that knowledge is constructed, not transferred (Simonson 2019). Stated another way, knowledge must be constructed in the mind of each individual learner (Treagust et al. 1996).

Guided inquiry employs a learning cycle based on 3 phases of inquiry: exploration of the model (which can be a graph, or data, or a picture), concept invention, and application (Karplus and Thier 1967; Abraham and Renner 1986). The goal of this learning cycle is to help students make connections to their prior knowledge while they are building (inventing) this new concept so that it is more firmly stored in long-term memory (National Research Council 2000).

It has been shown with test results from chemistry students that guided inquiry improved retention of actively-gained knowledge when compared to a lecture-only group (Vanags et al. 2013). Jensen and Lawson (2011) demonstrated that guided inquiry is especially effective when teaching biology students who start the course with lower reasoning ability as measured by responses to higher cognitive level test questions. Although the use of guided inquiry to promote content retention in anatomy has not yet been tested, these studies on related content suggest that the use of this technique should benefit anatomy students.

Since many community colleges have open enrollment (no minimum ACT or SAT score), many students come to class without the experiential background that would benefit them

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in anatomy. Additionally, community colleges have higher proportions of women and underrepresented minorities who are more likely to leave a STEM college major when faced with lecture-only classes (Rainey et al. 2019). Using active learning strategies in community college classrooms may be particularly beneficial for disadvantaged students. Haak and coworkers (2011) found that, while all introductory biology students benefited from an active learning, highly structured course design, the underrepresented minorities and economically disadvantaged students significantly closed the achievement gap when taught using this format.

Several studies have demonstrated use of guided inquiry during online instruction. One used guided inquiry as a home assignment with communication between class members occurring on a discussion board. The study evaluated their online conversations and demonstrated that the three stages of the learning cycle were occurring in this online environment (Lunsford 2008). A second study focused on the learning characteristics of students who chose guided inquiry over a video format and the ability of this educational method to promote belief change. Students with lower levels of academic entitlement, plus a growth mindset, did better with guided inquiry than with video (Barton and Chesley 2020).

It is unclear whether online delivery of guided inquiry will continue to foster topic retention and understanding as assessed using follow-up testing. This study used a two-group, post-test design to investigate this question in online synchronous anatomy classes at Salt Lake Community College.

Methods

Student Population

Salt Lake Community College (SLCC) is a large, multi-campus, public, two-year college located in Salt Lake County (population > 1 million). Approximately 60,000 students attend SLCC with 73% of those attending part-time. The average student course load is 6 class hours per semester. Forty-one percent of the students self-identify as working full time while the same percentage identify as working part-time. Fifty-four percent are first-generation college students and approximately 75% receive financial aid, indicating the general fiscal status of this student population. The student population is 27% minority with Hispanic being the largest group. The average student age is 23; however, a wide range of ages is found in each classroom. This is an open enrollment school meaning no minimum ACT or SAT score is needed to apply. All students are evaluated for basic Math, Writing, and English skills before class placement. Each semester approximately 600-700 students take anatomy in classes limited to 30 students with two 80-minute class sessions a week. These students also take a separate 3 hours per week cadaver-based laboratory class that is limited to 24 students per section.

This study was carried out in a total of 6 online Anatomy lecture classes (3 in Fall 2020 and 3 in Spring 2021) taught by the same instructor (VFR). The prerequisite for anatomy is college biology, meaning students have some college experience prior to reaching the anatomy course. This study was approved by the IRB Board of Salt Lake Community College (IRB # 00009578, approved January 2020). No identifying student information was used in this study.

Experimental Protocol

Sliding filament theory is taught during the 6th week of class after students have learned the names of the axial and peripheral muscles. The sliding filament theory guided inquiry activity developed by Brown was used (Brown 2015). This activity includes four models: the sarcomere, the molecular events of the contraction cycle (including the ATP), calcium binding, and the neuromuscular junction. Both semesters it was announced, in advance, that classes given at 8:30 am and 1 pm would feature the guided inquiry learning activity. Students preferring a lecture format came to the 10 am class. Students self-selected for the guided inquiry activity, as much as their schedules would allow. A total of 40 students chose to participate in guided inquiry activities while 103 participated in standard lectures.

Fall 2020 classes were delivered on the Webex platform while the Spring 2021 classes were on the Zoom Platform. Both platforms allow breakout groups which were utilized for the small group interactions (3-4 students each). Students were assigned to their groups by the online platform and neither the students nor the instructor influenced group makeup. Students remained in the same group for the whole activity. Both platforms allow the instructor to "break in" to a group in progress and allow the group members to call for help. During the guided inquiry activity, students were in their group 4 times; each time for 7 to 15 minutes. Between group sessions, the entire class participated in defining the concepts and instructions for the next breakout. The instructor visited each group during the first breakout and then only when requested by the students.

Two weeks later, all students completed a test that included questions related to the sliding filament theory. The sliding filament questions represented about 17% of a section test covering 6 book chapters and 7 class periods. All questions were written by the instructor. The test was administered online through the Canvas Learning Platform using the Proctorio online proctoring program. The points earned by each student on the related questions were divided by the total points available on this topic to create a percent correct for each student. Test questions covered a range of difficulty from memorization to application of the concepts. (Appendix 1).

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Data Analysis

Analyses were carried out using Jamovi, an open-source statistical software version 1.8.1 (www.jamovi.org). All tests were evaluated against an alpha level of 0.05. The distributions of grades in the guided inquiry and traditional lecture groups were first inspected for normality using the Shapiro Wilk test. Distributions deviated significantly from normal in the guided inquiry group (Shapiro-Wilk W (39) = 0.93, $p = 0.01$) and the traditional lecture group (W (102) = 0.93, $p < 0.001$). Levene's test indicated non-homogeneity of variances (F (1, 141) = 11.8, $p < 0.001$). As a result, group differences in grades were analyzed using the non-parametric Mann-Whitney U test, and effect size was estimated using rank biserial correlation.

Results

As shown in Figure 1, students participating in the guided inquiry activity (n=40) had a median score of 79.0% (mean = 77.0% $\pm$ 19.7 (SD)) on the topic questions. This was compared with a median score of 61% (mean = 61.4% $\pm$ 27.9 (SD)) for the lecture students (n = 103), a difference that was significant ($U = 1389$, $p = 0.002$). A rank biserial correlation of 0.33 suggested that this was a medium-sized effect. In addition, no students receiving guided inquiry instruction received a grade in the lower 2 quartiles in contrast to students in the traditional lecture group (Figure 2).

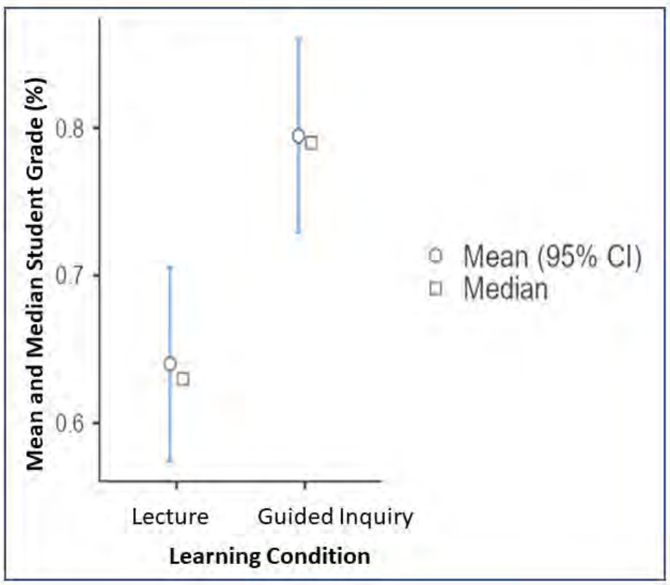

Figure 1. *Comparison of median and mean (+/- 95% confidence intervals) grades received by students in the lecture condition (n = 103) and the guided inquiry condition (n = 40), indicating a significant difference (p = 0.002) in student outcomes between the two conditions.*

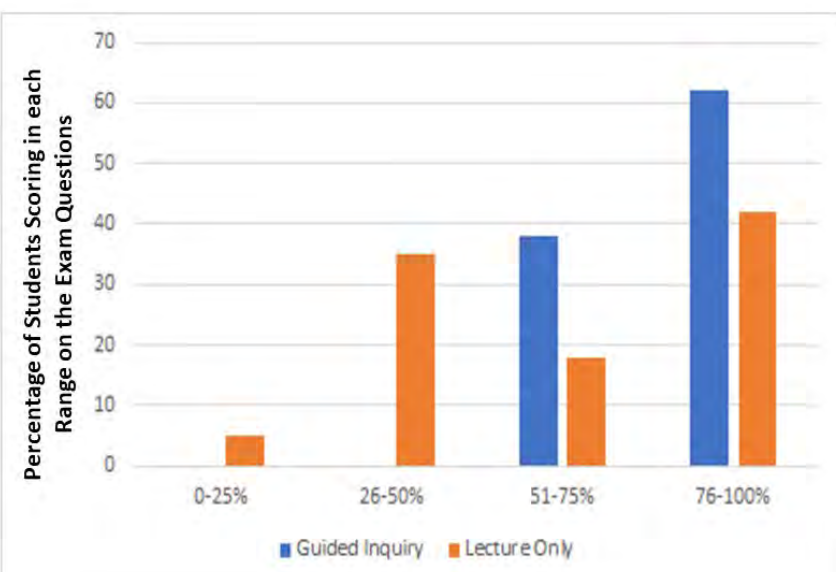

Figure 2. *Distribution of grades (%) received by students in the two online classroom conditions. Orange bars represent students in the lecture-only condition (n = 103) whereas blue bars represent students in the guided inquiry condition (n = 40).*

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Discussion

Anatomy and physiology classes are often high stakes courses for students because they act as gatekeepers to entering a healthcare curriculum. A new vocabulary must be learned, and there are a tremendous number of structures to memorize and difficult concepts to master. Students entering with low academic self-efficacy can struggle with the demands of this subject and their confidence in achieving a good grade. The guided inquiry active learning approach presents an opportunity to help these students gain confidence within a group of peers and in their ability to understand the concepts. The current study, though limited in student numbers, indicates that students retained knowledge better after guided inquiry than from standard lecture, likely due to the exercise of constructing knowledge instead of aiming to learn it passively. After the guided inquiry activity used for this study, students expressed a desire for more such activities.

Several challenges specific to online learning were encountered with the implementation of guided inquiry. During an in-person guided inquiry activity, the instructor can walk around the class unobtrusively listening and lending guidance to student groups who are struggling or are off-topic. There is an organic nature to the interactions. In contrast, during the online activity, the instructor cannot hear the breakout groups. Joining a group creates an abrupt break in the student discussion. Consequently, the instructor joined each group only once during the first breakout session. In addition, not being able to hear the students means a guess must be made as to when to end the groups.

Several caveats need acknowledgment. Students who did not attend class could later watch a video of the lecture-only class. For those in the guided inquiry activities, however, videos of breakout groups were not recorded and thus these class videos weren't available later to students. This contributed to the larger number of lecture-only students (n = 103) who didn't attend class but later watched the lecture. Students receiving guided inquiry instruction could also have reviewed the lecture video on their own, however, review of the zoom recording analytics indicates that they did not. Additionally, students self-selected for the guided inquiry activity which may have influenced the grades if academically stronger students disproportionally opted for the guided inquiry activity. Students viewing the guided inquire recorded grades in all but the bottom quartile suggesting a good mix of students. All these considerations may or may not confound the data presented.

Conclusion

The abrupt transition to online learning led to new questions about the efficacy of guided inquiry in the online teaching environment. This active learning method has long and reliable evidence-based support for improving student scores, retention, and class engagement in a variety of basic sciences as described in the introduction. This study also supports using guided inquiry in an online environment to benefit student retention of content, this time for the study of anatomy.

About the Authors

Vicky Rands is an Assistant Professor at Salt Lake Community College where she teaches Anatomy and Physiology to students focused on healthcare careers. She is a participant in the CAPER -NSF Grant research project coordinated by Murray Jensen, a professor at the University of Minnesota where he teaches entry-level physiology and conducts research on teaching and learning. Suzanne Hood is an Associate Professor in the Psychology Department at Bishop's University. Her research interests include how individual differences in psychological states affect academic performance. Ron Gerrits is a professor at Milwaukee School of Engineering. He is acting as a mentor in the CAPER project.

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APPENDIX: Test Questions on Sliding Filament Theory

1. The primary function of the T-tubules is to:

Allow for the generation of new muscle fibers

Allow the muscle membrane impulse to move deeper into the cell

Finish the muscle fiber contraction

Provide nutrients to the muscle fiber

2. Which of the following is not associated with the thin myofilament?

A. Actin

B. Troponin

C. Tropomyosin

D. Myosin

3. At the neuromuscular junction, all of these are true except:

A. The muscle impulse continues along the sarcolemma and down the T-tubules.

B. The synaptic cleft is the space between the nerve and the muscle.

C. The synaptic vesicles contain the neurotransmitter norepinephrine.

D. The receptors are located on the motor end plate.

4. What is attached to the thin filament in the sarcomere?

Endomysium

Z-line

M-line

Thick filament

5. What happens when ATP binds myosin?

A. Myosin binds troponin.

B. It releases from actin.

C. The myosin changes shape.

D. The power stroke occurs.

6. All of these are true about the role of ATP in muscle contraction EXCEPT:

A. ATP hydrolysis to ADP and Pi moves myosin to the cocked position.

B. ATP binds myosin.

C. When myosin bound to actin releases the ADP, the power stroke occurs.

D. ATP allows calcium to bind to troponin.

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7. The __________ [Select] **is the contractile unit inside the muscle fiber. This unit is made up of three parts.**
The __________ [Select] **filament is attached to the** _________ [Select] **which is the vertical "side" lines.**
The _______ [Select] **filament only attaches to the** ______ [Select] **when it is forming the cross bridge.**
(Dropdown Menu for each answer)

ANS 1 choices: sarcomere, sarcolemma, sarcoplasmic reticulum, myofibril

ANS 2 choices: thin, thick, M-line, Z-line

ANS 3 choices: Z-line, M-line, thick filament, thin filament

ANS 4 choices: thick, thin, small, large

ANS 5 choices: actin on the thin filament, troponin on the thin filament, Z disc protein

8. Put the steps of muscle contraction in order. Note: Some of the steps are listed for you! (For questions in italics, supply dropdown menu for students to choose correct answer)

1. An electrical impulse travels down the nerve fiber
2. A nerve impulse causes vesicles to release Acetylcholine into the synaptic cleft
3. Ach binds to receptors on the muscle membrane causing the electrical impulse to be transmitted to the muscle membrane
4. The electrical impulse inside the muscle cell causes the release of calcium ions from the sarcoplasmic reticulum
5. Ca++ ions bind troponin
6. Troponin rotates and moves tropomyosin off of the myosin binding site on Actin.
7. The myosin head binds the actin binding domain.
8. Myosin bends in two places, releasing ADP and pulling on the thin filament
9. The Z-lines are pulled closer together and the sarcomere gets shorter
10. The myofibril contracts

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