JOURNAL OF RESEARCH IN SCIENCE, MATHEMATICS AND TECHNOLOGY EDUCATION
DOI: 10.31756/jrsmte.633

Which course resources and student approaches to learning are related to higher grades in introductory biology?

Sarah J. Adkins, Kynadi Brasfield, Tam Tran, J. Jeffrey Morris, and Samiksha Raut

The University of Alabama at Birmingham, United States of America

Abstract: For the undergraduate introductory biology student, performance on exams as measured by course grades is a strong determinant of downstream success in the biology major and ultimately retention in Science, Technology, Engineering, and Mathematics fields. But what helps students do well on exams? Previous studies have connected introductory biology student success with course resources like pre-class reading guides (worksheets to accompany textbook material) or supplemental instruction (where upper-level peers with some training in student learning re-teach content). However, many of these studies do not also connect student course outcomes with how students feel about learning, referred to as Student Approaches to Learning (SAL). Here, we not only investigate the association between course resources and exam grades, but also consider the relationship between SAL and student grades. Over a span of two spring semesters, students in a large southeastern research university introductory biology course (N= 307) completed information related to ten course resources they used during the semester and further assessed SAL via the Biggs Revised Study Process Questionnaire (R-SPQ-2F). Our results suggest students who earned a higher overall grade in the course were significantly more likely to self-report higher attendance in optional peer-led supplemental instruction and, unexpectedly, were less likely to use pre-class reading guides. These students were more likely to report finding course material interesting, whereas students with lower overall final grades were more likely to report trying to memorize course material. Given that the efficacy of resources can vary based on the student, we not only encourage the promotion of resources supported by empirical evidence, but also encourage a deeper understanding of the SAL which shapes resource use.

Keywords: *Introductory Biology; Undergraduate; Course resources; Performance; Student Approaches to Learning; Revised Study Process Questionnaire*

Introduction

Imagine you are an undergraduate student walking into your first large introductory biology class. After maneuvering around the dozens of classmates finding their way to their seats, you finally find a spot yourself. You look up to the syllabus projecting on the front of the screen and listen to your instructor begin telling you how to be successful in this course. You have a degree’s worth of science classes to go so you know doing well in this class is an important first step toward graduation. But which course resources should you pick? This question can determine not just how the next 16 weeks transpire but could change whether you complete your degree.

It is increasingly important to quantify the effectiveness of course resources and learning approaches, particularly in introductory biology which is often an introductory requirement across Science, Technology, Engineering, and

Mathematics (STEM) degrees. The percentage of students who receive Ds or Fs or withdraw from introductory biology courses (known as the DFW rate) ranges from 20 to 30% at universities across the United States (Bell, 2018; Freeman et al., 2014; Ueckert et al., 2011; Theobald et al., 2020). In other words, up to a third of students who begin introductory biology fail or drop out not only from this course but also from STEM. Considering grades in introductory biology predict the retention of a student as a biology major, high DFW rates are a cause for concern (Creech & Sweeder, 2012; AAAS, 2009; Freeman et al., 2014). Indeed, we know that current Grade Point Average (GPA), rather than performance on specific courses, is the strongest indicator of future success in courses throughout college (Creech & Sweeder, 2012) and is correlated with differences in study skills (Elliot et al., 1990; Hassanbeigi et al., 2011). Research is still emerging about how students achieve higher grades at the beginning of their college career. Understanding why and how students succeed on introductory course exams is fundamental towards improving outcomes for less successful students in these high enrollment courses.

Understanding Student Approaches to Learning (SAL) helps researchers better identify trends in study resource use. The Biggs Bifactor Model (Biggs et al., 2001) is a framework which measures attitudinal variables that could influence study habits by showing differences between surface and deep learning constructs. Deep learning approaches indicate an intrinsic understanding of meaning such as “I find most new topics interesting and often spend extra time trying to obtain more information about them” (Biggs et al., 2001). In contrast, surface learning approaches involve motivations extrinsic to the course material itself, such as “My aim is to pass the course while doing as little work as possible” (Biggs et al., 2001). Other models that include surface and deep approaches also include either transfer or achievement levels (Frey et al., 2017). For example, Frey and colleagues identified transfer learning to include problem solving, debate, and Socratic seminars whereas deep learning includes reciprocal teaching, metacognition, and concept mapping (Frey et al., 2017). Research has shown that students who used active and deeper strategies scored higher on their exams even though they studied for less time than those who used surface level approaches (Walck-Shannon et al., 2021). Deep and surface approaches within Biggs’ framework both had subscales that included motive items and strategy items (Biggs et al., 2001). Motive items include “intentions” whereas strategy items describe “behaviors”.

After revising, rewording, and reducing the deep approach and surface approach categories, Biggs et al formulated the two-factor Study Process Questionnaire (SPQ-2F) (Biggs et al., 2001). A good fit to the two-factor structure (i.e., deep vs. surface) was indicated through a confirmatory factor analysis (Biggs et al., 2001). Subsequent research has used a revised questionnaire (RSPQ-2F) to answer several SAL research questions such as problem-based learning and outcomes from active-learning reforms (Verkade et al., 2016) (Jeong et al., 2019). Here, we apply the RSPQ-2F to understand students’ study processes and the impact of different SAL on student course outcomes in introductory biology. Improving our understanding of the interactions between three factors – course resources, SAL, and grades – is crucial to advance a student-centered learning landscape, as students’ viewpoints are where the task of improving academic performance begins. In the context of our student population, we were interested in exploring the following two questions:

1. What patterns of course resource use are associated with higher or lower grades?
2. What learning approaches (surface vs. deep) are associated with higher or lower grades?

Given that researchers believe there is no "magic-bullet" study strategy that is effective across all student groups (Hora & Oleson, 2017), our work may suggest new directions for how educators with similar course contexts foster success in their courses.

Methods

School and course description

The University of Alabama at Birmingham (UAB) is a research-intensive doctoral-granting university in the southeastern United States with approximately 20,000 part- and full-time students. Fall and spring semester courses met twice a week for 75-minute sessions over 16 weeks. Each semester, a section of Introductory Biology I enrolls approximately 200 students from various STEM related majors. This course serves as a core prerequisite for various professional school requirements. The first of a two-course sequence, the content in Introductory Biology I included cell biology, molecular biology, and evolution with no prerequisites. In lecture, the professor (author S.R.) utilized active learning strategies such as in-class student response system questions, think-pair share, and one-minute papers (Tanner, 2013). Many course resources advocated by the professor had been recommended through evidence-based practices at other institutions, including supplemental instruction (SI) (Rath et al., 2017), pre-class Reading Guides (Lieu et al., 2017) and Mastering Biology (Rayner, 2008). Lecture grades were dependent upon four evenly spaced non-cumulative exams with 50 multiple choice questions each. All students simultaneously enrolled in the lecture and laboratory components of the course, where lecture and lab constitute 70% and 30% of the final course grade, respectively. This study considered only cumulative raw exam grades from the lecture course. Spring semester was chosen so that students had a pre-existing GPA coming into the course, in contrast to Fall semester first-year students who do not yet have a college GPA. This study was repeated in Spring 2017 and Spring 2018.

Study Motives and Participants

This work began in 2017 as a Center for the Integration of Research, Teaching, and Learning "Teaching As Research" project with the intention of filling a gap in the education literature whose results may benefit future UAB students. This study was approved by the Institutional Review Board (IRB) at UAB under protocol #170414011. All students enrolled in the course, regardless of their study participation, received 4 bonus points on their Exam 4. In Spring 2017, 168 students were enrolled in the course after the add/drop date, and 139 consented to participate. In Spring 2018, 193 students were enrolled in the course and 168 students consented to participate. At the end of their spring 2017 or 2018 semester, all consenting students in Introductory Biology I completed post-semester surveys. While demographic information was not collected from the 2017 students, the second iteration in 2018 asked consenting students to additionally complete a demographic questionnaire (see demographics in Supplemental Table 1) after a roundtable discussion with education researchers at the Society for the Advancement of Biology Education

Research (SABER) conference. All surveys were administered in the absence of any of the authors on this study or their instructors to mitigate the chances that students modified their results based on a perception of being observed. All paper-based surveys were administered on the final day of class prior to students taking the final exam, so that student attitudes would not be affected by their performance regarding the exam. Responses included student names so that they could be matched with student's end-of-semester final grades but named survey results were not identifiable to instructors or researchers.

Description of Resources

Various course resources (See Box 1) were recommended by the professor throughout the semester to enhance student success in the introductory biology course. Each student enrolled in the course had equal access to these resources on a voluntary basis and it was exclusive of any course credit towards the final course grade.

Surveys and Implementation

Our study employed two survey instruments. First, we created a UAB-specific class-resource questionnaire (CRQ) that inquired about the use of specific optional course resources offered to students (Box 1). As a survey did not exist to answer this course specific research question and the timing of its intended administration did not allow for an assessment of its validity or reliability, this survey designed by the course instructor was edited for readability by two professors, four students, and a CIRTL course of graduate students prior to its administration. Second, the RSPQ-2F (Biggs et al., 2001) is a 20-item validated Likert scale survey chosen for students to assess how often they identify with surface and deep learning constructs. Answers were coded on the following 5-point scale where 0 = "This item is never or only rarely true of me," to 4 = "This item is always or almost always true of me." Notably, the subfactors of Biggs' bifactor model is inconclusive (Socha & Sigler, 2014) and though the RSPQ-2F is a commonly used instrument for education research (Bana & Fatima, 2019), concerns about the way the instrument is traditionally scored relating to issues in word interpretation, item structure, and lack of course specificity have been raised (Johnson, 2019; Johnson et al., 2021). For this reason, we looked at each specific item line rather than broadly categorizing students using the Deep – Surface score differential, which aggregates survey responses (Johnson, 2019; Johnson et al., 2020).

In spring 2017, participants completed our CRQ and the RSPQ-2F. In spring 2018, participants completed our CRQ, the RSPQ-2F, short free response reflections, and a demographic information survey. Surveys were completed on the last day of class before the final course exam.

Box 1

Activities encouraged by the Introductory Biology I professor and included on the Class Resource Questionnaire

1. Attending supplemental instruction (SI) – Bi-weekly optional out-of-class meetings with practice questions led by peers who were successful in the course in a previous semester; this is a university-sponsored program

2. Attending Teaching Assistant (TA) instruction— Bi-weekly optional meetings with practice questions led by peers who were successful in the course in a previous semester; this is a professor-led initiative

3. Attending CIRTL Fellow online instruction – Weekly optional online question and answer session led by biology graduate student

4. Asking questions to instructors – Questions could be asked through office hours or by email

5. Using Mastering Biology by Pearson – a supplemental resource that accompanies the textbook and requires a pre-bought access code, includes assigned textbook tutorials, self-quizzes, and animations

6. Studying in Groups - Students were encouraged to consult and study with peers outside of class time

7. Reading the textbook – Latest edition of textbook (Reece et al., 2014) recommended for regular use, as instruction and course notes derive from textbook information

8. Completing Reading Guides – Posted in the LMS Canvas system for access before the start of every chapter, included open-ended questions that assist a student's comprehension of the assigned textbook chapter

9. Completing CIRTL fellow review guides – Exam study guide of close-ended questions created by biology graduate student

10. Completing supplemental instruction (SI) worksheets – worksheets are designed by SI leaders and TAs based on the course content, mimicking the exam format

11. Completing Vocabulary lists – Posted in the LMS Canvas system for access before the start of every chapter, defining topical vocabulary in their own words, as the chosen textbook does not include an extracted list

Statistical Analysis

Data was analyzed using linear mixed effects models, with "semester" as a random effect, in R version 1.3.1073, using the *lme4* package (R Development Core Team, 2014). From the overall data set, 10 partial responders (3.2% of n=307) were omitted for analysis. For the first research question, fixed effects considered were the CRQ resource responses represented as categorical factors (e.g., "Biweekly)". We also considered a version of this model in which the CRQ predictors were represented as continuous numerical data (ex. "Biweekly" = "4", "Daily" = "8"). To answer the second research question, fixed effects were numeric RSPQ Likert responses. Initial models were run using all fixed effects with no interaction terms and were refined by removing predictors that were not significant; p values of equal or less than 0.05 from a comparison (using the *anova* function in R) of the full model with a particular drop-out model were considered to indicate the dropped variable was a significant predictor of a student's final grade. After removing non-significant predictors, we then introduced interaction terms between the remaining fixed effects and assessed the significance of these terms by *anova* comparison with the interaction-free refined model. Reported results are derived from fully refined models containing no non-significant fixed effects.

For each of our research questions, we additionally ran models on just the 2018 cohort (n=147, 48% of n=307), as this cohort provided demographic information for further analysis. 2018 student demographic responses, excluding GPA and class standing/year, were binned as binary factors ("yes" or "no") including: underrepresented minority in STEM (Black/African American, Hispanic/Latino/Latina, Native American/Pacific Islander), female students, and first-generation students. These demographics were analyzed as fixed effects with the significant predictors from the previous analysis, with potential demographic predictors culled using the refinement protocol described above.

In addition to the survey instruments, participants were also prompted to answer an open-ended class resource question: "What study methods did you use to study effectively for BY123 (including any not already mentioned)?" This question was answered by 286 (93% of n=307) students. Mentions of course resources being effective, helpful, or useful were included in the coding whereas resources that students claimed were ineffective or not useful were not included in this analysis, as this question was not asked uniformly across students. For student free responses, two researchers (S.A. and T.T.) independently extracted categorical themes from the entire dataset using Glaser's Grounded Theory (Brownell et al., 2015) and themes were discussed until a consensus was reached. The raters scored a randomized sub-set of responses together to establish a pattern from which the rest of the data could be analyzed by one rater. Themes which provided additional insight to quantitative results or those shared by students who did well in the course were of particular interest.

Results

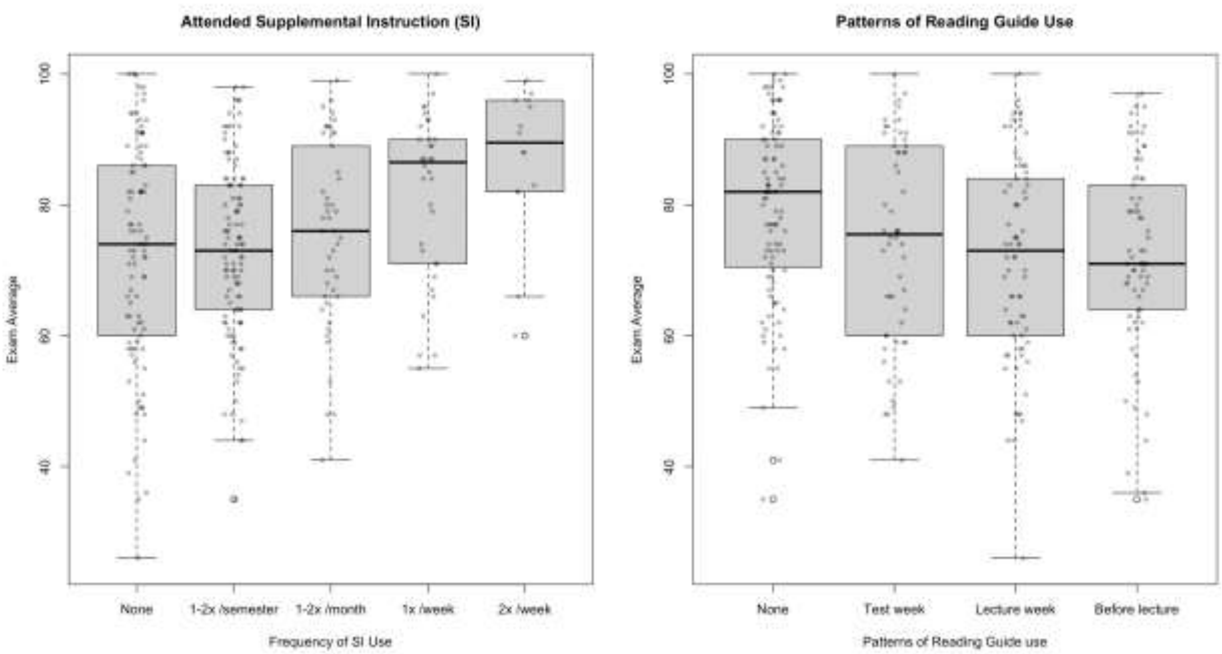
Resource use

Self-reported supplemental instruction (SI) attendance as numeric predictor was found to be significantly positively related to course grade (LME, p = 0.0004) (Figure 1). Based on our quantified refined LME models, the highest response for SI attendance (i.e., the student used SI biweekly) had an effect of 10 points, equivalent to a letter grade, on the student's overall course grade compared to a student who did not use SI. When these were analyzed as factorial variables, the most pronounced effect was from biweekly SI attendance (LME, p=0.0008, effect size 16.47 per Likert unit on grade), followed by weekly SI attendance (LME, p=0.008, effect size 9.31per Likert unit on grade). The free response question indicated 36 students (n=307) reported SI sessions or worksheets were among their most helpful course resources for studying in this course (these 36 students had a course average of 78±0.016% but the class average is not significantly lower, at 74.69%). A student who earned a 100 in the course said the effective resources were: "SI sessions, reading test, reading guides, and vocab lists," whereas a similar sentiment was shared by a student who earned a 46.5%: "Group study, SI, quizlet, book, reading guides, and I still failed."

Compliance to instructor encouraged patterns of reading guide use (i.e. a higher score meant using the reading guide before the relevant lecture compared with completing it the week before the test) was negatively related to overall course grade (LME, p = .029) (Figure 1). Based on the quantitative version of the LME model, each unit indicating the instructor encouraged practice of reading guide use would have a 2.27-point detriment to the student's overall grade; since there were 4 levels, this corresponds to a roughly letter grade advantage for students who never used the reading guides, relative to those who used the guides as suggested. Results were similar when reading guide responses were treated as factorial, where use of reading guides immediately before class or the week of class was correlated with a -6 reduction in overall course grade (LME, p<0.05). Reading guides were noted in the free response answer to be effective for 46 students (their collective course average was 73%). Some students explained in more detail how they used the reading guides, like this student who earned an 80%: "I read the chapters before attending lecture. I filled out the reading guides and studied some of the vocabulary terms that were not familiar to me"; or this student who earned a 76%: "I also always did the reading guides and vocab before coming to class". However, most responses listed the resource without further explanation.

Figure 1

Self-reported attendance in supplemental instruction (left) and patterns of reading guide use (right) as related to student exam averages. (Best practices of supplemental instruction (top) are related to higher overall course grade whereas professorial best practices of Reading Guide (bottom) use are related to lower overall course grade which was an average of four lecture exams).



Though using vocabulary lists was not found to be significant according to the p=0.05 cutoff when treated as a numeric (LME, p=.08), vocabulary list use was related to lower course grades when modeled as a factor. Students who reported using vocabulary lists the week of the test were likely to have scored 10 points lower on their exams compared with peers who did not use vocabulary lists at all (LME, p= 0.02). From the free response data, 19 students of n=307 (6%) mentioned vocabulary lists as one of their most effective study strategies, and together their course average was 74%. One student, who earned a 48% in the course, said "I read the chapters and went over the vocab list”. However, the exact same sentiment was shared by a student who earned a 97.8% when they said their effective strategies were “reading book and doing vocab”.

Lastly, students who reported studying in groups the week of the test were predicted to score 6 points lower on their exams than those who did not report studying in groups (LME, p = 0.012) according to our factorial, but not our quantitative, model. No other resources (see “Box 1“ for complete list) were significantly related to overall course grade. When assessing the effects of only the 2018 cohort where demographic variables were present in the analysis, we found being an underrepresented minority in STEM fields (non-white and non-Asian race/ethnicities) had a modest negative effect on grade (LME, p = 0.006, effect size -6.0 on grade), and previous GPA had a substantial effect on grade (LME, p<0.001, effect size 19 per unit on grade). However, there was no significant interaction between these demographic data and students’ reported study habits.

We also made some interesting observations from the free response data that were not captured in the survey data. We found that students who passed the course based on exam average were significantly more likely to note fewer study methods or course resources were effective to their studying (average resources noted as effective was 1.3) compared with those who failed the class, who noted almost twice as many resources (their average resources noted as effective was 2.7) (p=0.00002). A noteworthy theme mentioned by students who earned high grades in the course which emerged from our qualitative analysis not mentioned elsewhere in our survey was drawing, diagraming, or graphing. Nine students (3% of n=307), who together had an average course grade of 87%, reported drawing as an effective strategy. These responses ranged from the simple “graphing notes” to the quite thorough: “Before exams, I reread chapters, focusing on comprehension rather than simply memorizing. I tried to visualize important processes in my head and often tested myself by attempting to draw them out on paper.” We also observed some responses that used terminology not captured in our categories exclusive to resource use. In “Table.1” we compile the responses of both successful and unsuccessful students in the course.

SAL

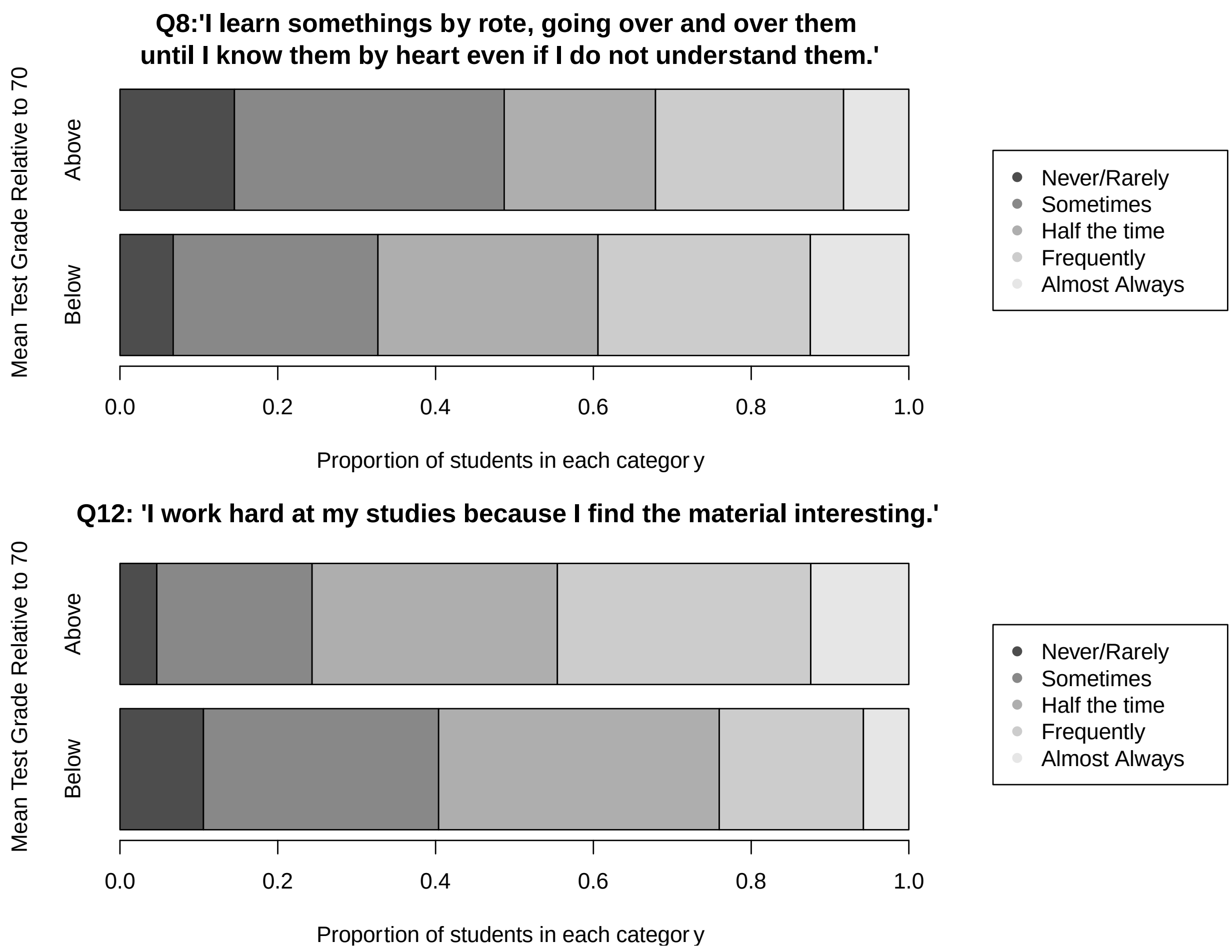
Significant negative associations were found between grade and students reporting memorizing by rote without understanding (RSPQ-2F Q8; LME, p = 0.0007). A student who said they always learned by rote memorization was predicted to score 9.9 points lower in the course than a student who said they never learned this way. On the other hand, students who reported finding the material interesting scored 9.7 points higher than those who did not (RSPQ-2F Q12; LME, p = .017).

Table 1

Quotes excerpts from students from Introductory Biology I who mentioned "understanding" or "still not doing well [regardless of their effort]".

Excerpts from students who mentioned "understanding" material	**Excerpts from students who mentioned "still not doing well"**
• Reading the book, devoting time to fully understanding the material. (**98.4%**) • Reading the text and understanding it, mastering biology quizzes online. (**100%**) • Study group. It was the most beneficial for showing me how much I needed to study to better understand concepts or if I understood. When I studied individually, the reading guides were the most helpful although I often went beyond what they asked. (**93%**) • I would use the online CIRTL when I didn't understand a topic and if I still wasn't satisfied, I googled it. (**83%**) • Read the book when I didn't understand a topic. (**66%)** • Focused on concepts that I didn't really understand well. (**97.2%)** • I would occasionally SI and review sessions if I did not understand a concept. (**79.5%**) • The reading guides helped me understand key concepts so I can go back and learn them in depth. Access to old SI worksheets. Teach myself/peers (sometimes my stuffed elephant) the material. **(68.5%)**	• Group study, SI, quizlet, book, reading guides, and I still failed. (**46.5%**) • I got a tutor to help me understand the material, I also used mastering biology, quizlet, and study in study groups and that still did not help my grade. (**49%**) • I always read the chapters and made note cards as well as study guides. I went to a few SI sessions and did not find them helpful. Lecture also didn't help even though I attended almost everyone. I spend 5+ hours a week studying and still did poorly. (**54.5%**) • I used the book and used reading guides and vocab lists. Basically everything [the professor] said and then some. Sadly, none of this was effective and did not prepare me for the test. (**62%**)

Figure 2
Trends between student responses on RSPQ-2F questions 8 and 12 as a function of their final grade. **(**Likert scales are indicated by darker gray (never/rarely) to lighter gray (almost always))



Analyzing the same model with only the 2018 cohort with demographics showed slightly different results. In this analysis, significant associations were shown between grade and admission to learning by rote memorization (LME, $p = 0.002$, effect size is -3.16 per Likert unit on grade). The only significant demographic predictor was former GPA, which significantly influenced the effect of using rote memorization (RSPQ-2F Q8) on course grade (LME, $p = 0.010$, effect size =-4.9524 per Likert unit on grade). In other words, the GPA and self-reporting of memorizing revealed a bimodal distribution: students who had a high GPA benefitted from rote memorization, whereas students with lower GPAs who admitted to memorizing would have earned a lower grade in the course.

Lastly, agreement to the statement “I make a point of looking at most of the suggested readings that go with the lectures" was found to be a significant predictor of course grade in the 2018 cohort (LME, $p=0.01$) with an effect size of 2.67 per Likert unit on grade. No demographic effects were found to have a significant interaction with responses to this statement.

Discussion

This study sought to understand how the study methods and SAL of introductory biology students during their out-of-class study time impacted their performance on exams. Results from this study provide evidence-based suggestions for educators engaged in providing advice to introductory biology students.

Strategies and SAL associated with success

The largest indicator for success for the students in this study was their university GPA. Many of the students in our study were first years who had taken one semester previously. Unsurprisingly, previous research corroborates how previous grades are a good predictor of future grades (Creech & Sweeder, 2012; Elliot et al.,1990) and there are indications that first-years are often novice learners who may not understand that deeper study habits are crucial in being successful during college years (Sebesta & Speth, 2016). While we did not ascertain high school GPA, previous biology experience, or concurrent schoolwork, those factors may be contributory. Interestingly, our work shows that students with higher GPA were more likely to take surface level approaches to studying, but that students less successful in the course were also more likely to use these same surface level strategies.

We found that student grades were positively related to self-reported SI attendance, which supports previous findings (Rath et al., 2007; Ogden et al., 2003; Dawson et al., 2014). Free response results show that even lower-achieving students recognized that SI was an effective study tool. At UAB, this resource is monitored through the Vulcan Materials Academic Success Center (VMASC). VMASC not only vets their SI leaders in terms of content knowledge, but also trains them in some metacognitive approaches to learning. This may account for why students had a stronger preference for the effects of SI rather than TA review sessions or the online chatroom content review, as TA peer leaders were not vetted through the same pedagogical process. Since this finding, author S.R. has supplemented TA positions with Biology Learning Assistants (BLA) which bear resemblance to the SI and TA model but with even more advanced pedagogical training (Otero et al., 2010; Goertzen et al., 2011; Talbot et al., 2015). Preliminary results indicate this BLA model is on par with student outcomes from this study (data not shown), results which are corroborated by previous studies (Alzen et al., 2017; Clements et al., 2022).

Although drawing was not a course resource directly inquired about in our CRQ, we found that nine students, who on average earned an 87%, mentioned drawing or diagramming as among their most effective study strategies. Former work has demonstrated the connection between drawing and conceptual understanding in the biology classroom (Quillin & Thomas, 2015) which could in part explain why higher achieving students were likely to self-report drawing as an effective strategy. A growing body of evidence suggests the inclusion of art in biology courses can heighten engagement (Adkins-Jablonsky et al., 2021; Milkova et al., 2013), but the relationship between art, biology education, and SAL remains unexplored.

Related to SAL, our results broadly support the hypothesis that deeper SAL are correlated with higher achievement. Higher achieving students reported deeper understanding and lower achieving students reported frustration in using resources without success (Table 1). It is essential for students, especially those trying to overcome low achievement on exams, to develop deeper level study approaches (Ye et al., 2016). Rote memorization, a surface level approach, without deeper understanding was correlated to lower course grade in both of our student cohorts. Students may adopt these approaches because they are focused on assessment activities, rather than learning activities (Genc & Tinmaz, 2013). These feelings may be especially salient in courses where summative assessments comprise a majority of the course-grade. Thus, active-learning courses with low-stakes assignments have the capacity to redirect SAL for lower achieving students. We also found higher achieving students were more likely to find course material interesting (Figure 2), a deeper motive approach, which may be related to experiences students have had prior to college (VanMeter-Adams et al., 2014) or their motivations for pursuing their degree. Considerable effort has been undertaken to understand student interest "in the sciences" (Romine et al., 2014) and interest has been shown to improve with increasing active-learning pedagogies (LaForce et al., 2017).

Strategies associated with poor performance

There was a negative correlation between using professor-provided reading guides according to the professor's recommendation (that is, completing them before the relevant lecture) and final course grade. However, students who reported via the RSPQ that they read assigned readings prior to the lecture were more likely to have higher grades. Some of our results seemingly contradict former work (Lieu et al., 2017) which demonstrated reading guide use prior to lectures correlated with higher course grades. Notably, our work did not specifically investigate the degree to which reading guides were completed or how they were used which could in part explain the differences in results. Regardless, these results show that general advice for students to use reading guides before class may not itself be enough to increase student outcomes. One idea is that students could be instructed to annotate notes and check for understanding while reading the textbook rather than to simply complete reading guides (Ye et al., 2016).

Similarly, vocabulary lists were introduced to the course because the instructor noted the course textbook did not provide vocabulary lists following each chapter. Survey results indicated increased vocabulary list use was related to a lower course grade. Former work corroborates this evidence, showing vocabulary lists have been ineffective for other cohorts of students (Armbruster et al., 2009). We suspect that an emphasis on vocabulary lists may encourage rote memorization instead of the contextualized understanding that is needed for content mastery. For this reason, vocabulary lists have subsequently been de-emphasized in this course.

Students who reported studying in groups the week of their test did not score as highly on the exams as those who did not study in groups. While group studying is often commendable in and outside of the classroom (Ye et al., 2016), students who depend on others to teach them information may not fare as well on examinations. While we do not know the degree to which students who reported group studies were dependent on others to study, it is possible that these cohorts may have depended on passive approaches without spaced repetition, which has been shown to enhance individual learning (Yuan, 2022). On the other hand, lower achieving students were also more likely to indicate tutors and online content tools as effective resources. Former work has shown when tutors accentuate content over the learning process, students do not do as well (De Grave et al., 2002), which could have been the case with these student's tutors. Practice quizzes (Fisher et al., 2020) especially via online content tools (Easy Notecards/Quizlet/Study blue/CourseNotes) also encourage memorizing content, which may be why lower achieving students defaulted to their use "Table 1". Moreover, considering students who did not pass their exams reported a significantly higher number of course resources were effective, it is possible students were not using resources as effectively or had a cognitive mismatch between their approach and their true ability as compared with higher achieving students.

Outlook

Using study habits scores and attitude inventories, which are known to be effective in predicting academic performance (Credé & Kuncel, 2008), we found specific study habits are related to course outcomes. While this work only covered one course at one institution, our findings are consistent with previous research (Credé & Kuncel, 2008). Notably, metacognitive Student Approaches to Learning (SAL) were disproportionately adopted by high-achieving students (Table 1). While not all advice can help every student (Gurung et al., 2010), instructors teaching self-regulation and metacognition could especially help lower-achieving students (Sebasta & Speth, 2017; Tomanek & Montplaisir, 2004). For instance, periodic in-class workshops could be offered that drive home the idea that student's self-assessment and self-reflection is the key to success in introductory biology courses rather than memorization. In addition, instructors implementing more low-stakes assessments instead of depending solely on high stakes multiple choice exams could shift student learning approaches (Tomanek & Montplaisir, 2004). Taken together, these strategies could show students that active learning should transcend the classroom (Hora & Oleson, 2017) to benefit them in their introductory biology course, degree program, and beyond.

Acknowledgements

This work was completed as a "Teaching As Research" project towards UAB's Center for the Integration of Research, Teaching, and Learning (CIRTL) Scholar Certificate. We extend our gratitude to Dr. Julia Austin at UAB, roundtable attendees at the Society for the Advancement of Biology Education Research conference in 2017, and the CIRTL Forum abstract reviewers in 2019. We would also like to acknowledge our undergraduate student Nykierra Taylor for her assistance with the literature review. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship Program [Grant No. 1450078] to S.J.A and a UAB Center for Teaching & Learning Teaching Innovation and Development Award Program to S.R (2014).

References

AAAS (2010). Vision and Change: A Call to Action. Washington, DC AAAS www.visionandchange.org/VC_report.pdf.

Adkins-Jablonsky, S. J., Arnold, E., Rock, R., Gray, R., & Morris, J. J. (2021). Agar art: a CURE for the microbiology laboratory. Journal of Microbiology & Biology Education, 22(2), e00121-21.

Alzen, J. L., Langdon, L., & Otero, V. (2017). The Learning Assistant model and DFW rates in introductory physics courses. In Physics Education Research Conference Proceedings (pp. 36-39).

Armbruster, P., Patel, M., Johnson, E., & Weiss, M. (2009). Active Learning and Student-centered Pedagogy Improve Student Attitudes and Performance in Introductory Biology. CBE—Life Sciences Education, 8(3), 203-213. doi:10.1187/cbe.09-03-002.

Bana, K., & Fatima, K. (2019). Comparing the learning approaches using biggs revised study process questionnaire (R-SPQ-2F) among dental undergraduates. JPDA, 28(02), 69.

Bell, J. (2018). Analysis of DFW Rates for the Fall 2013-Spring 2017 CSU Chico Classes. https://www.csuchico.edu/ir/_assets/documents/by-the-numbers/bell-analysis-of-dfw-rates-in-classes.pdf

Biggs, J., Kember, D., & Leung, D. Y. (2001). The revised two-factor study process questionnaire: R-SPQ-2F. British Journal of Educational Psychology, 71(1), 133-149.

Brownell, S. E., Hekmat-Scafe, D. S., Singla, V., Seawell, P. C., Imam, J. F. C., Eddy, S. L., Stearns, T., Cyert, M. S. (2015). A High-Enrollment Course-Based Undergraduate Research Experience Improves Student Conceptions of Scientific Thinking and Ability to Interpret Data. CBE—Life Sciences Education, 14(2), ar21. doi:10.1187/cbe.14-05-0092

Credé, M., & Kuncel, N. R. (2008). Study habits, skills, and attitudes: The third pillar supporting collegiate academic performance. Perspectives on psychological science, 3(6), 425-453.

Creech, L. R., & Sweeder, R. D. (2012). Analysis of student performance in large-enrollment life science courses. CBE—Life Sciences Education, 11(4), 386-391.

Dawson, P., van der Meer, J., Skalicky, J., & Cowley, K. (2014). On the effectiveness of supplemental instruction: A systematic review of supplemental instruction and peer-assisted study sessions literature between 2001 and 2010. Review of Educational Research, 84(4), 609-639.

De Grave, W. S., Dolmans, D. H., & Van Der Vleuten, C. P. (2002). Student perspectives on critical incidents in the tutorial group. Advances in Health Sciences Education, 7, 201-209.

Elliott, T. R., Godshall, F., Shrout, J. R., & Witty, T. E. (1990). Problem-solving appraisal, self-reported study habits, and performance of academically at-risk college students. Journal of Counseling Psychology, 37(2), 203-207. doi:http://dx.doi.org.ezproxy3.lhl.uab.edu/10.1037/0022-0167.37.2.203

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings Of The National Academy of Sciences, 111(23), 8410-8415.

Fisher, M. R., Vemu, S., Oh, Y., & Cole, D. (2020). Identifying Differences in Learning Strategies by Demographics and Course Grade in a Community College Context. Retrieved January 29, 2021, from https://www.nsta.org/journal-college-science-teaching/journal-college-science-teaching-septemberoctober-2020/identifying

Hassanbeigi, A., Askari, J., Nakhjavani, M., Shirkhoda, S., Barzegar, K., Mozayyan, M. R., & Fallahzadeh, H. (2011). The relationship between study skills and academic performance of university students. Procedia-Social and Behavioral Sciences, 30, 1416-1424.

Hora, M. T., & Oleson, A. K. (2017). Examining study habits in undergraduate STEM courses from a situative perspective. International Journal of STEM Education, 4, 1-19.

Jeong, J. S., González-Gómez, D., Conde-Núñez, M. C., & Gallego-Picó, A. (2019). Examination of Students' Engagement with R-SPQ-2F of Learning Approach in Flipped Sustainable Science Course. Journal of Baltic Science Education, 18(6), 880-891.

Frey, N., Fisher, D., & Hattie, J. (2017). Surface, deep, and transfer? Considering the role of content literacy instructional strategies. Journal of Adolescent & Adult Literacy, 60(5), 567-575.

Genc, Z., & Tinmaz, H. (2013). Understanding the Learners’ Study Process: A Vital Step Toward Better Learning. Procedia-Social and Behavioral Sciences, 83, 1049-1053.

Goertzen, R. M., Brewe, E., Kramer, L. H., Wells, L., & Jones, D. (2011). Moving toward change: Institutionalizing reform through implementation of the Learning Assistant model and Open Source Tutorials. Physical Review Special Topics-Physics Education Research, 7(2), 020105.

Gurung, R. A., Weidert, J., & Jeske, A. (2010). Focusing on how students study. Journal of the Scholarship of Teaching and Learning, 28-35.

Johnson, S. N. (2019). Cognitive Processes in Undergraduate Anatomy and Physiology Courses.

(Publication No. 2495) [Doctoral dissertation, Clemson University] All Dissertations.

https://tigerprints.clemson.edu/all_dissertations/249

Johnson, S. N., Gallagher, E. D., & Vagnozzi, A. M. (2021). Validity concerns with the Revised Study Process Questionnaire (R-SPQ-2F) in undergraduate anatomy & physiology students. PloS One, 16(4), e0250600.

LaForce, M., Noble, E., & Blackwell, C. (2017). Problem-based learning (PBL) and student interest in STEM careers: The roles of motivation and ability beliefs. Education Sciences, 7(4), 92.

Lieu, R., Wong, A., Asefirad, A., & Shaffer, J. F. (2017). Improving exam performance in introductory biology through the use of preclass reading guides. CBE—Life Sciences Education, 16(3), ar46.

Milkova, L., Crossman, C., Wiles, S., & Allen, T. (2013). Engagement and skill development in biology students through analysis of art. CBE—Life Sciences Education, 12(4), 687-700.

Ogden, P., Thompson, D., Russell, A., & Simons, C. (2003). Supplemental instruction: Short-and long-term impact. Journal of Developmental Education, 26(3), 2.

Otero, V., Pollock, S., & Finkelstein, N. (2010). A physics department's role in preparing physics teachers: The Colorado learning assistant model. American Journal of Physics, 78(11), 1218-1224.

Quillin, K., & Thomas, S. 2015. Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. CBE-Life Sciences Education, 14(1), es2.

RStudio Team. (2016). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

Rath, K. A., Peterfreund, A. R., Xenos, S. P., Bayliss, F., & Carnal, N. (2007). Supplemental Instruction in Introductory Biology I: Enhancing the Performance and Retention of Underrepresented Minority Students. CBE—Life Sciences Education, 6(3), 203-216. doi:10.1187/cbe.06-10-0198

Rayner, G. (2008). Using 'mastering biology' to formatively improve student engagement and learning in first year biology. Sch Biolog Sci, Monash Univ.

Reece, J. B., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Jackson, R. B. (2014). Campbell biology (No. s 1309). Boston: Pearson.

Romine, W., Sadler, T. D., Presley, M., & Klosterman, M. L. (2014). Student Interest in Technology and Science (SITS) survey: development, validation, and use of a new instrument. International Journal of Science and Mathematics Education, 12(2), 261-283.

Sebesta, A. J., & Bray Speth, E. (2017). How should I study for the exam? Self-regulated learning strategies and achievement in introductory biology. CBE—Life Sciences Education, 16(2), ar30.

Socha, A., & Sigler, E. A. (2014). Exploring and “reconciling” the factor structure for the Revised Two-factor Study Process Questionnaire. Learning and Individual Differences, 31, 43-50.

Talbot, R. M., Hartley, L. M., Marzetta, K., & Wee, B. S. (2015). Transforming undergraduate science education with learning assistants: Student satisfaction in large-enrollment courses. Journal of College Science Teaching, 44(5), 24-30.

Tanner, K. D. (2013). Structure matters: twenty-one teaching strategies to promote student engagement and cultivate classroom equity. CBE—Life Sciences Education, 12(3), 322-331.

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D.L., Cooper, J.D., Dunster, G. Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. Proceedings of the National Academy of Sciences, 117(12), 6476-6483.

Tomanek, D., & Montplaisir, L. (2004). Students' Studying and Approaches to Learning in Introductory Biology. CBE—Life Sciences Education, 3(4), 253-262. doi:10.1187/cbe.04-06-0041

Ueckert, C., Adams, A., & Lock, J. (2011). Redesigning a large-enrollment introductory biology course. CBE—Life Sciences Education, 10(2), 164-174.

VanMeter-Adams, A., Frankenfeld, C. L., Bases, J., Espina, V., & Liotta, L. A. (2014). Students who demonstrate strong talent and interest in STEM are initially attracted to STEM through extracurricular experiences. CBE—Life Sciences Education, 13(4), 687-697.

Verkade, H., & Lim, S. H. (2016). Undergraduate science students' attitudes toward and approaches to scientific reading and writing. Journal of College Science Teaching, 45(4), 83.

Walck-Shannon, E. M., Rowell, S. F., & Frey, R. F. (2021). To what extent do study habits relate to performance?. CBE—Life Sciences Education, 20(1), ar6.

Yuan, X. (2022). Evidence of the Spacing Effect and Influences on Perceptions of Learning and Science Curricula. Cureus, 14(1).

Ye, L., Shuniak, C., Oueini, R., Robert, J., & Lewis, S. (2016). Can they succeed? Exploring at-risk students' study habits in college general chemistry. Chemistry Education Research and Practice, 17(4), 878-892.

Appendix

SUPPLEMENTAL MATERIAL

Supplemental Table 1. Demographic information on consenting Spring 2018 students.

Gender	105 (Female) 61 (Male)
Race/Ethnicity	120 (White/Caucasian or Asian) 44 (American Indian, Black/African American, Native Hawaiian/Pacific Islander, Hispanic/Latinx)
First Generation Status	140 (One or both parent/guardians earned at least a 4-year degree) 24 (Parents/legal guardian had a maximum of either a 2-year degree or had no college)
Class Standing	129 (Freshmen) 19 (Sophomores) 9 (Juniors) 5 (Seniors) 2 (5th year Seniors) 3 (Post-baccalaureate)

Class Resources Questionnaire (CRQ). For questions 1-6, circle how often you used each resource ON AVERAGE to study for BY 123. Please circle the *one* most appropriate response to each question. Do not spend a long time on each item: your first reaction is probably the best one. Do not worry about projecting a good image. Your answers are CONFIDENTIAL and will NOT negatively impact your grade.

	None	**Semesterly**	**Monthly**	**Weekly**	**Bi-Weekly**
1. Attended SI instruction:	Did not use	1-2 times per semester	1-2 times a month	1 time a week	2 times a week
2. Attended TA review sessions:	Did not use	1-2 times per semester	1-2 times a month	1 time a week	2 times a week
3. Attended online sessions:	Did not use	1-2 times per semester	1-2 times a month	1 time a week	2 times a week
4. Asked questions to professor or BY assistants out of class (e-mail/office visit)	Did not use	1-2 times per semester	1-2 times a month	1 time a week	2 times a week

5. Mastering Biology:	Did not use	1-2 times per semester	1-2 times a month	1 time a week	2 times a week
6. Group study:	Did not use	1-2 times per semester	1-2 times a month	1 time a week	2 times a week

Notice that the format has changed slightly for questions 7-10. For questions 7-10, circle how often you used each resource ON AVERAGE to study for BY 123.

	None	**As soon as possible**	**Within week of lecture**	**After lecture**
7. Textbook	Did not use	Before relevant lecture	Within week of lecture	A week before test day
8. Reading Guides	Did not use	Before relevant lecture	Within week of lecture	A week before test day
9. SI sheets/Mock Exams	Did not use	Day posted	Within week of lecture	A week before test day
10. Vocab lists	Did not use	Day posted	Within week of lecture	A week before test day

Please write a personal and appropriate response to the following question. Do not worry about projecting a good image. Your answers are CONFIDENTIAL and will NOT negatively impact your grade.

1. Open ended question for the space below: **What study methods did you use to study the most effectively for BY123 (including any not already mentioned)?**

Revised Study Process Questionnaire (R-SPQ-2F)

This questionnaire has several questions about your attitudes towards your studies and your usual way of studying. There is no *right* way of studying. It depends on what suits your own style and the course you are studying. It is accordingly important that you answer each question as honestly as you can. If you think your answer to a question would depend on the subject being studied, give the answer that would apply to the subject(s) most important to you. The letters alongside each number stand for the following response. A — this item is *never* or *only rarely* true of me; B — this item is *sometimes* true of me

C — this item is true of me about *half the time;* D — this item is *frequently* true of me; E — this item is *always* or *almost always* true of me

Please CIRCLE the *one* most appropriate response to each question. Do not spend a long time on each item: your first reaction is probably the best one. Please answer each item. Do not worry about projecting a good image. Your answers are CONFIDENTIAL.

	A. ***never* or *only rarely***	***B.*** ***sometimes***	***C.*** ***half the time***	***D.*** ***frequently***	***E.*** ***always/ almost always***
1. I find that at times studying gives me a feeling of deep personal satisfaction.	A	B	C	D	E
2. I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.	A	B	C	D	E
3. My aim is to pass the course while doing as little work as possible.	A	B	C	D	E
4. I only study seriously what's given out in class or in the course outlines.	A	B	C	D	E
5. I feel that virtually any topic can be highly interesting once I get into it.	A	B	C	D	E
6. I find most new topics interesting and often spend extra time trying to obtain more information about them.	A	B	C	D	E
7. I do not find my course very interesting so I keep my work to the minimum.	A	B	C	D	E
8. I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.	A	B	C	D	E
9. I find that studying academic topics can at times be as exciting as a good novel or movie.	A	B	C	D	E

	A. ***never*** **or** ***only rarely***	***B.*** ***sometimes***	***C.*** ***half the time***	***D.*** ***frequently***	***E.*** ***always/ almost always***
10. I find I can get by in most assessments by memorizing key sections rather than trying to understand them.	A	B	C	D	E
11. I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.	A	B	C	D	E
12. I work hard at my studies because I find the material interesting.	A	B	C	D	E
13. I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes.	A	B	C	D	E
14. I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.	A	B	C	D	E
15. I believe that lecturers shouldn’t expect students to spend significant amounts of time studying material everyone knows won’t be examined.	A	B	C	D	E
16. I come to most classes with questions in mind that I want answering.	A	B	C	D	E
17. I make a point of looking at most of the suggested readings that go with the lectures.	A	B	C	D	E

18. I see no point in learning material, which is not likely to be in the examination.	A	B	C	D	E
19. I find the best way to pass examinations is to try to remember answers to likely questions.	A	B	C	D	E

Corresponding Author Contact Information:

Author name: Samiksha Raut

Department: Biology

University, Country: The University of Alabama at Birmingham

Email: sraut@uab.edu

Please Cite: AUTHOR, AUTHOR, AUTHOR, AUTHOR (2023). Which course resources and student approaches to learning are related to higher grades in introductory biology? *Journal of Research in Science, Mathematics and Technology Education*, 6(3), 175-196. DOI: https://doi.org/10.31756/jrsmte.633

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Data Availability Statement: The raw data and code supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics Statement: This study was approved by the Institutional Review Board (IRB) at the University of Alabama at Birmingham under protocol #170414011.

Author Contributions: All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Received: February 28, 2023 ▪ Accepted: August, 26, 2023