It's About Time: Exploring the dose-dependent effects of active learning on students of different social personalities in an upper-level biology course

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Abstract

Active learning is the new standard for teaching in higher education. As more faculty seek to expand their teaching practices by including active learning activities that promote higher levels of learning, many are doing so in small doses by temporarily postponing traditional lectures in favor of group activities. While there is evidence demonstrating that active learning practices can facilitate higher performance and information retention, our previous work showed that social personality differences can affect an individual's performance in group-oriented active learning exercises. The results from this work indicated a possible dose-dependent effect driving the correlations observed between performance and social personality compared to passive lectures. This study builds on our previous work by analyzing if hosting comparatively few active learning classes is leading to a dose-dependent effect on student performance by personality type in the active learning setting. Our findings from this research demonstrate that social personality-based

differences in performance on topics taught using active learning diminish with increased exposure to active learning. We also found that students of all personality types perform better on memorization-based questions than on higher-order questions in general, but that their performance on higher-order thinking questions improved after participating in active learning..

Keywords: Pedagogy, IPIP, Introvert, Extrovert, Ambivert

1. Introduction

Active learning is transforming higher education. Its use has been correlated with improved learning gains, performance enhancement, reduced failure rates, and in some cases gives students a greater sense of belonging (Ballen et al., 2018; Freeman et al., 2014; Terenzini et al., 2013; Haak et al., 2011). Because of this, active learning is rapidly becoming the gold standard for higher education. While there is a collective push to incorporate active learning in college curriculum, the term "active learning" encompasses a wide range of different tools and strategies (e.g., collaborative learning, cooperative learning, flipped classroom designs, problem-based learning, computers and technology, whiteboard space) and how it is implemented can impact its efficacy towards achieving higher levels of understanding and information retention over time (Styers, Van Zandt, and Kayden, 2018, Asok et al., 2016, McCormick, Clark, and Raines, 2015, Kim et al., 2012, Michael, 2006). For example, the use of high-tech screen-sharing applications and computers in an active learning setting may improve student success in courses pertaining to information technology where they are a necessity for hands-on instruction, while imparting no additional benefit over low-tech alternatives (e.g., whiteboards) in other courses (Soneral & Wyse, 2017). Gender, race, and social personality factors have also been shown to affect how students receive the active-learning learning environment, playing an important role in their participation in group settings and, ultimately, their understanding of material. Therefore, certain types of active learning

techniques may benefit some groups of students, but not others (Beckerson et al., 2020; Ballen et al., 2018; Marbach-Ad et al., 2016). Furthermore, how students engage with active learning activities may also influence learning gains (LaDage et al., 2018). This then begs the question: how should universities approach recommendations for implementing active learning strategies for different populations of students, and for the university as a whole?

It is unlikely that a practice as diverse as active learning will have a one-size-fits-all solution for implementation in the classroom. The complexity of active learning practices combined with the wide breadth of departments, materials, and learning goals, as well as the diversity of student populations, makes a targeted approach towards best practices far more feasible. One way in which we can begin to build a repertoire of best practices is to analyze how different active learning strategies affect different groups of students at the classroom and individual levels. While research into active learning consistently shows improved performance on average at the classroom level (Freeman et al., 2014; Haak et al., 2011; Kortz et al., 2008; Crouch & Mazur, 2001) across multiple disciplines (Hung 2017; Morosan et al., 2017; Favero 2011; Prince, 2004), these studies are not standardized for different forms of active learning practices, nor do they account for performance at the individual level. While overall class performance may improve with the addition of active learning exercises, exercises that are group-oriented may introduce barriers for those of different social-phobias, student background, race, and personalities, unintentionally leading to classroom isolation (Castilla et al., 2017; Wood 2014; Plenty & Jonsson, 2016; LaBelle & Johnson, 2018).

Studies as far back as the 1970's have demonstrated that different majors tend to have student cohorts with differing group personality averages (Vedel, 2016; Vedel et al., 2015; Horn et al., 1975). For example, STEM majors as a whole tend to be less extroverted than those who major in the arts and humanities (Vedel, 2016; Balsamo et al., 2012). There are also intraspecific differences in levels of extroversion within departments as demonstrated by Beckerson et al., where students of ecology tested two points above the average in extroversion and students of microbiology tested two points below the average in extroversion (2020). Taking a tailored approach towards recommendations for active learning methods by program, or even through class-specific methods, may result in advising for smaller group activities (e.g., think-pair-share) or non-collaborative alternatives (e.g., clicker questions) in more introverted fields, and large group activities for more extroverted fields.

In our previous work, we explored how student social personality impacts performance and reception of group-based active learning in periodic learning sessions on junior/senior level STEM majors (Beckerson et al. 2020). Our research team found that introverted students were less likely to perform as well on assessments that tested their knowledge of material covered in small group exercises (conducted in a new active learning space but not in the normal classroom) compared to their extroverted peers, whose performance improved with active learning instruction. However, while our work demonstrated a clear and significant effect of social personality on active learning performance, it was yet unclear whether these effects were the direct result of social personality on group-based learning, or whether they may have been the result of a dose-dependent effect for working in the active learning setting. The amount of time spent in the active learning classroom may therefore have differing effects on individuals, based on social personality markers, that make

them faster or slower at adapting to the new learning environment, especially given that the junior/senior level students who participated in our previous study have spent the majority of their academic career in traditional lecture-style classrooms. We therefore hypothesized that the performance gap we had previously observed between introverts and extroverts may be reduced if the entire course was held in an active learning classroom performing active learning assignments, a hypothesis that is backed by results from the student feedback results from our previous work that showed no preferential differences among personality types for active learning curriculum.

With the completion of the Belknap Academic Building at the University of Louisville, outfitted entirely with active learning classrooms with capacity ranging from 20-124 students, we were finally able to put this hypothesis to the test. In this study, we conducted an upper-level biology course entirely in an active learning classroom and incorporated more active learning exercises and group-based activities than in our previous work. This setup not only allowed us to identify whether or not there is a dose-dependent effect on student performance in active learning settings by personality type, but also provided us with a large enough sample size to test whether social personality affected student performance on questions requiring differing levels of Bloom's Taxonomy (i.e., memorization or higher-order thinking questions). To capitalize on this opportunity to use our data to address a multivariate hypothesis, our results were analyzed through three different phases of questioning: Phase I) Did personality affect performance on exam questions pertaining to active learning? Phase II) Do personality differences correlate with performance on higher-ordered questions? And Phase III) Did students perform better on higher-order thinking questions after active learning?

By conducting this research, we hope to highlight personality effects at the class and individual levels in effort to facilitate a more inclusive approach towards incorporating active learning in the classroom on a case-by-case basis. This work helps instructors better understand how personality influences performance in the classroom and helps to pave the way for studies on best practices for applying group-oriented active learning.

2. Materials and Methods

2.1 General Procedural Framework

To identify whether or not limited exposure to an active learning environment facilitates a dose-dependent response between students with different social personality, this study was conducted entirely in an active learning classroom (high-dose) and results were compared to previously published work in which active learning was implemented in two sessions (low-dose) throughout the semester. Both courses were taught by the same professor in effort to reduce variables that arise from different teaching ideologies and experience. Furthermore, this instructor has been trained in active learning techniques through the Delphi Center for Teaching and Learning and had been using similar active learning materials for several semesters prior to initiating this research. The research took place in the Belknap Academic Building at the University of Louisville, a building constructed to house active learning environments. The active learning classroom used in this study featured 11 groups of 3 conjoined tables (Figure 1-A) seating up to 6 students each for a total capacity of 66 students. Each of the eight tables on the periphery were equipped with their own computer monitor (Figure 1-B), and the classroom was fitted with two large computer monitors on the walls (Figure 1-C). In addition to computer monitors, the classroom was also fitted with a front and back-facing projector which could be utilized with automated drop-down projector

screens at either end of the classroom (Figure 1-D). Students were also supplied with personal whiteboards (Figure 1-E) as well as given access to use the whiteboards on the wall to present group data (Figure 1-F), and each table had a terminal to charge and connect electronic devices to access the computer monitor displays through screen-sharing technology (Figure 1-G).

- Figure 1 -

Although the course was held in an active learning setting and group participation was encouraged throughout the semester, only eight class sessions were specifically tailored to utilize active learning tools. These eight class sessions were divided across four units with two group-oriented active learning classes per unit. Topics covered during these active learning sessions were in line with topics that were covered in passive learning style lectures taking place in the active learning setting, but included specific material not covered in the lecture for testing purposes. To facilitate participation during these group-oriented sessions, each group was graded on both completion and accuracy of the associated project for that class period, as well as through peer evaluations from other individuals in their groups. Groups were changed 4 times over the semester with efforts made to have students interact with new group members over the semester. To gage information retention from these active learning sessions, four in-class unit exams were given throughout the semester with questions divided between lower-order, memorization-style questions, defined in this study as the bottom two tiers of Bloom's Taxonomy, and higher-order thinking style questions, defined in this study as the top 4 tiers of Bloom's Taxonomy, for both the topics covered in the group-oriented active learning sessions and the passive learning style lectures. To prevent confounding variables due to copying and other forms of cheating during the exam, four forms of each exam were made and distributed in a manner so that no two people sitting

next to one another had the same exam form, and the exams were proctored. These exam forms differed in the orders of the questions and the arrangement of the answers but contained the same questions and correct answers. All personal information used in this analysis, including personality trait and test scores, was blinded throughout the semester to prevent any biases during grading. The information was only unblinding after collection of all data points was completed to perform statistical analyses.

Each student enrolled in the fall 2019 BIOL 357 General Microbiology class was given an informed consent form to allow them to opt into the study. In total, 56 students agreed to participate in this study, out of 65 enrolled. Participating students also were given the option to remove their data from the study after initial enrollment at any time, although none did. All participating students took the IPIP Big Five Measure of Personality test to identify their social personality category using the same cutoff values for level of extroversion as were used in our previously published work (Beckerson et al., 2020), in which students scoring 10-23 are categorized as Introverts, 24-37 are categorized as Ambiverts (previously referred to as "Neithers" in Beckerson et al., 2020), and 38-50 are categorized as Extroverts. Given that no statistically significant effect was observed for the other four personality metrics in Beckerson et al., 2020, only level of extroversion was used in this study.

2.2 Statistical Analyses

Statistical analysis of the data was carried out using R 3.6.2 with the packages 'lme4', 'lmertest', and 'ggplot2'. Exam, group ID, and participants were treated as random effects, while social

personality was treated as a fixed effect. To test for interactions between these variables, a linear mixed effect model was first used with the assumption that response variables followed Gaussian distribution to screened for patterns across exam scores by exam keys, active learning session groups, and by unit before comparison with social personality scores using analysis of variance (ANOVA) tests. Questions were coded as 'memorization' when they addressed fundamental knowledge questions that were directly presented in class, either orally or on slides. 'Comprehension' questions were categorized thusly if they required comparing facts or definitions. Questions were considered 'higher-ordered' when students had to evaluate methods, synthesize conclusions from facts or observations, analyze data in charts, tables, or graphs, or determine possible effects of perturbations in systems, or determine possible outcomes in various situations, all of which were neither discussed directly in class nor presented to students. We also screened the scores for normal distribution using the R commands 'qqnorm' and 'qplot' to verify normality. The data for exam scores was then tested by question type (memorization or higher order learning) and social personality type (Introvert, Ambivert, or Extrovert) using a series of ANOVAs to test for significant effects. The resulting variables, subcategories, data classification, and effects are listed in Table 1.

- Table 1 -

3. Results

3.1 Distribution of Personality Type

The results from the IPIP Big Five Measures of personality were consistent and within the normal distribution of personality types across the 56 students who participated (Figure 2A). Using the same range of personality scores from Beckerson et al., 2020, these individuals were categorized

into 3 personality types; Introverts, Ambiverts, and Extroverts, with 11, 30, and 15 students falling into each category, respectively (Figure 2B). While the distribution of IPIP scores fell into a normal distribution, more Ambiverts were categorized on the higher end of the range (24-37), leading to a higher average score of 31.125 compared to the 28.091 average of the class in our previous study (Figure 2C).

- Figure 2 -

3.2 Does performance on active learning assignments predict exam performance?

Preliminary statistical analyses were performed using linear mixed-effects models to screen the data for irregularities in the raw scores, exam keys, and group patterns to account for any significant performance differences between exams that may be due to differences in day, material covered, or answer key of the exam. The data demonstrated that there was a statistically significant difference between overall performance across the four different exams (p = 2.9e-2). Exams 1 and 3 had higher performance with average scores of 77.14% and 77.39%, respectively, and Exams 2 and 4 had lower average scores of 72.54% and 72.66%, respectively. These results also showed a significant pattern of decreasing scores for active learning-based questions across the semester (p = 3.9e-4), along with passive learning questions (p = 2.5e-3), with the exception of questions from Exam 3 which explains why Exams 1 and 3 had similar averages. These decreasing trends can be explained by a gradual increase in difficulty level of exams across the semester, a product of the cumulative nature of material in this course. Initial screening of the data ruled out any correlations between personality type and in-class participation during active learning lectures. The average active learning assignment group scores were used as a metric for in-class participation for each individual and compared to their average exam performance. Individuals were then delineated by

personality type. Results demonstrate a positive correlation between active learning assignment scores and exam performance; however, no personality-specific trend was observed and therefore does not act as a confounding variable on exam performance by personality type (Figure 3).

- Figure 3 -

3.3 Did personality affect performance on exam questions pertaining to active learning? (Phase I)

When exam performance was evaluated by dividing each exam into two groups of questions, questions pertaining to material covered using active learning exercises and questions regarding material covered using a passive learning lecture style, and compared across the different categories of social personality, there was no statistically significant trend observed ($F_{2,55}$ = 3.93e-1, p = 6.75e-1, ns) (Figure 4). This is in contrast to findings from our previous "low-dose" study in which lectures took place primarily in a passive learning style lecture hall with only two supplemental active learning sessions throughout the semester (Figure 4). Type III analysis of variance with Satterthwaite's methods showed no statistical significance ($F_{2,55}$ = 3.93e-1, p = 6.75e-1, ns) in the "High Dose" comparison between active/passive learning question performance with regards to personality types while the "Low Dose" study showed a significant effect ($F_{2,32}$ = 3.16, p = 3.10e-2).

- Figure 4 –

3.4 Do differences in personality correlate with performance on higher-ordered questions? (Phase II)

When comparing the performance on exam questions divided into either memorization level or higher-order thinking level questions by personality type, we found no statistical difference between performance between Introverts, Ambiverts, or Extroverts ($F_{2,55}$ = 1.46 e-1, p = 8.64e-1) (Figure 5). There was however a statistically significant difference between performance on memorization questions versus higher-order thinking questions for the class as a whole ($F_{1,55}$ = 35.67, p = 4.09e-3) with students performing better on memorization questions (average scores 79.22, 79.02, 76.83 for Introverts, Ambiverts, and Extroverts, respectively) than on higher-order thinking questions (average scores 69.16, 69.08, 67.60 for Introverts, Ambiverts, and Extroverts, respectively), regardless of personality type (Figure 5). We therefore see little evidence that personality plays a role in how students perform on active or passive learning under these conditions but we do see evidence that all students performed better on the lower-order thinking questions.

- Figure 5 -

3.5 Did students perform better on higher order thinking questions after active learning? (Phase III)

In addition to a consistent trend of better performance on memorization questions for the class as a whole, our Phase III results also demonstrated a significant effect between the style of lecture and exam performance by question type ($F_{1,55}$ = 51.07, p = 2.55e-12). Further one-way ANOVA testing showed that average exam scores for memorization questions were statistically higher for questions pertaining to material taught through traditional passive style lectures, with an average score of 80.97%, when compared to questions pertaining to material taught through group-oriented active learning lectures, with an average score of 72.39 ($F_{1,55}$ = 16.00, p = 7.60e-5) (Figure 6). The inverse was true for higher-order thinking questions with students performing statistically better

on higher-order thinking questions for material covered in group-oriented active learning lectures, with an average score of 72.39, compared to material covered in traditional passive learning lecture, with an average of 65.76 ($F_{1,55}$ = 27.745, p = 2.29e-7) (Figure 6).

- Figure 6 -

We also noted that students tended to do worse on memorization-style questions when the information is covered in an active learning environment when compared to a passive learning environment (Fig. 6). This observation is not well supported in published literature but we speculate this trend may be due to an increase in critical thinking regarding information covered in active learning exercises which leads students to a deeper understanding of the material and can sometimes confuse or overload them with information, e.g., students thinking about it too hard. Students might also expect exam questions covering information from active learning exercises to be more complex or deeper than a simple memorization question and feel the "easy" answer cannot be right for a complex questions.

4. Discussion

After our initial research into the effect of student social personality on performance in the active learning setting was concluded for the Fall semester of 2018, our group identified a statistically significant difference in exam performance amongst social personality types; however, given the low-dose nature of the study in which students were asked to participate in only two active learning sessions throughout the semester, our group wondered what effect exposure to active learning may have had on students willingness to participate and learn from an active learning session in a study with so few sessions. In this follow-up study, we aimed to eliminate this dose-dependent variable by hosting the entire class in the active learning classroom as well as implementing a total of eight

group-oriented active learning exercises for each participant across the semester. Our findings under this new "high-dose" approach demonstrate results much more consistent with other pedagogical studies in three major ways.

First, the social personality effect observed in our first low-dose active learning study, in which introverts performed better on exams after attending traditional passive lecture style classes while extroverts performed better after group-oriented active learning classes and ambiverts did not exhibit preference either way, is not present in our findings from this high dose study. Interestingly, individuals categorized as extroverts in this study performed worse on questions pertaining to active learning material than those categorized as extroverts in the 2018 "low dose" study. This could be interpreted as a negative effect of continuous active learning on extrovert performance; however, variations in test materials, the introduction of 6 new active learning exercises in this study compared to the 2018 study, year-to-year variations in the student populations, and a larger number of students tested in our current study all introduce variables that can lead to differences in class averages. While we can say with statistical accuracy that there was no difference between performance on questions pertaining to active learning or passive learning material for extroverts, we cannot draw a conclusion on whether or not hosting the class entirely in an active learning setting negatively affects overall exam performance for extroverts, especially given the wealth of prior pedagogical research demonstrating the opposite is true.

Despite the uncertainty pertaining to overall exam performance between semesters, the loss of observable differences between performance on exam questions covering active learning material by personality type has important ramifications for lecturers who are beginning to adopt active learning practices as supplemental learning in their traditional lecture style courses. This

research demonstrates that there may be a significant dose-dependent effect on students with different social personalities when active learning classes are only implemented in small doses, specifically in the performance of introverts and introverted-leaning ambiverts. Therefore, our findings support the concept that complete revamping of courses to facilitate a consistent active learning class environment, one complete with frequent active learning practices, may be advisable.

The second important result from our findings involves the consistency of student social personalities amongst classes and across semesters. Results from the IPIP Big Five Measures of Personality test for extraversion showed a much higher average score of 31.125 for the 2019 Fall semester compared to the 28.091 average of the 2018 Fall class in our previous study. This result demonstrates that class averages for personality traits not only differ across majors and across classes within a department, but also within classes across different semesters. This finding indicates that it may be impossible to make simple recommendation for best practices at a departmental level as previously hoped; however, as the IPIP Big Five metrics are often used as an introspective, metacognitive tool for students as well, having students take this short quiz at the beginning of each semester may be useful for the students to increase meta-awareness and improve buy-in towards active learning setting. This information can also be useful for the instructor to implement formative adjustments to lecture practices across semesters. By utilizing these questionnaires, the instructor can gage which active learning practices may be most beneficial for that particular cohort of students. Furthermore, it may be useful to provide students with hand-outs or electronic resources which succinctly advise them on the strengths or weaknesses of their personality traits in group-based projects. Helping students understand how their personality traits

may influence group dynamics and perceptions may help students gain useful new skills for the workforce or professional school post-graduation, especially as many programs and careers require group-oriented work. We would like to note that some of the data presented had a high degree of variability (i.e. Figure 4). This could be explained by the fact that students are not only extraverted/introverted but also have multiple facets to their personalities that can contribute to these findings. Unfortunately, it is impossible to account for all personality traits in experimental design in the classroom but this is an interesting field of exploration for the future.

Finally, this study also demonstrated that despite a statistically significant trend showing that students performed better on memorization-style questions pertaining to material covered in traditional passive lecture style lessons and better on higher-order thinking questions pertaining to material covered in group-oriented active learning classes regardless of social personality, students performed better overall on memorization style questions regardless of teaching method. This finding is consistent with other pedagogical research that identify these higher-order thinking tasks, although more effective for long term retention and application of material, as more difficult in general (Jensen et al., 2014; Krathwohl, 2010). This trend towards higher performance on memorization questions is also likely impacted by the fact that this study involved an upper-level biology course, in which many of the participants are third or fourth year students that have been indoctrinated with traditional passive lecture style instruction. Therefore, it is plausible that students are simply accustomed to studying large lecture style material and answering lower order thinking questions on their exams. This further highlights the importance of revamping university lecture halls to implement active learning to provide students with the highest quality instruction possible, and to do this early in the curriculum with adequate instructional support. It also suggests

that instructors should try and focus their active learning time on activities that cover conceptual material and use traditional lecture-style teaching for dissemination of factual information.

The collective results from this research project suggest that designing active learning exercises needs to be considered carefully for any course on a case-by-case basis; however, due to the small sample size of our study, more research is needed to elucidate the true significance of dose dependency in active learning. As we continue to learn more about how active learning impacts students' education, and more types of exercises are invented to help facilitate higher levels of learning, it will become more and more important to create a set of best practices for when and how often to add active learning materials to the classroom. By continuing to dive deeper into factors that play a role in how students receive instruction, beyond the macro-institution and departmental levels traditionally used to understand the impact of active learning across many classes and periods of time, researchers can begin to offer such alternatives to a one-size-fits-all approach.

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Figure 1. The active learning classroom setup. Each group consisted of 6 chairs and 3 tables (A). Groups near the wall were given access to their own computer monitor (B) while groups in the middle were given access to the larger wall mounted monitors (C). The classroom was fitted with two projectors facing either end of the classroom (D) to display class instructions. Students were also provided with personal whiteboards at their tables (E) and group whiteboards on the walls of the classroom (F), as well as docking devices to charge and connect their electronic devices (G).

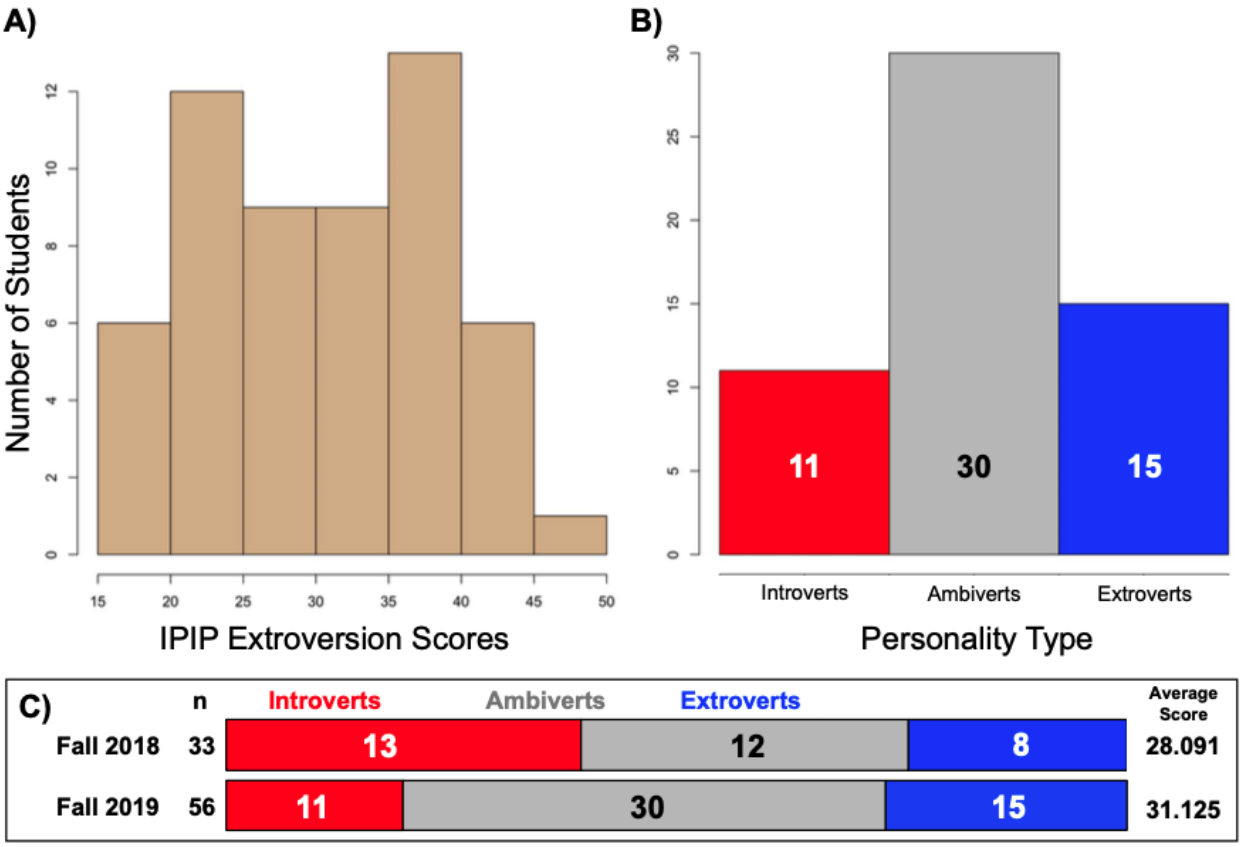

Figure 2. Distribution of results from the IPIP Big Five Measures of Personality scores for level of extroversion. A) depicts the number of students by bins of scores grouped by every 5 points. B) shows the results after categorization of students using the cutoff values in Beckerson et al., 2020, with scores between 10-24 categorized as Introverts, scores between 24-37 categorized as Ambiverts (previously "Neithers" in Beckerson et al., 2020), and scores between 38-50 categorized as Extroverts). C) outlines a comparison of personality type distribution between 357 General Microbiology students as a percent of the total number of participating students from the fall of 2018 (Beckerson et al., 2020) and the fall semester of 2019. Average scores for the level of extroversion on the IPIP Big Five Measures of Personality are shown to the right of personality type distributions.

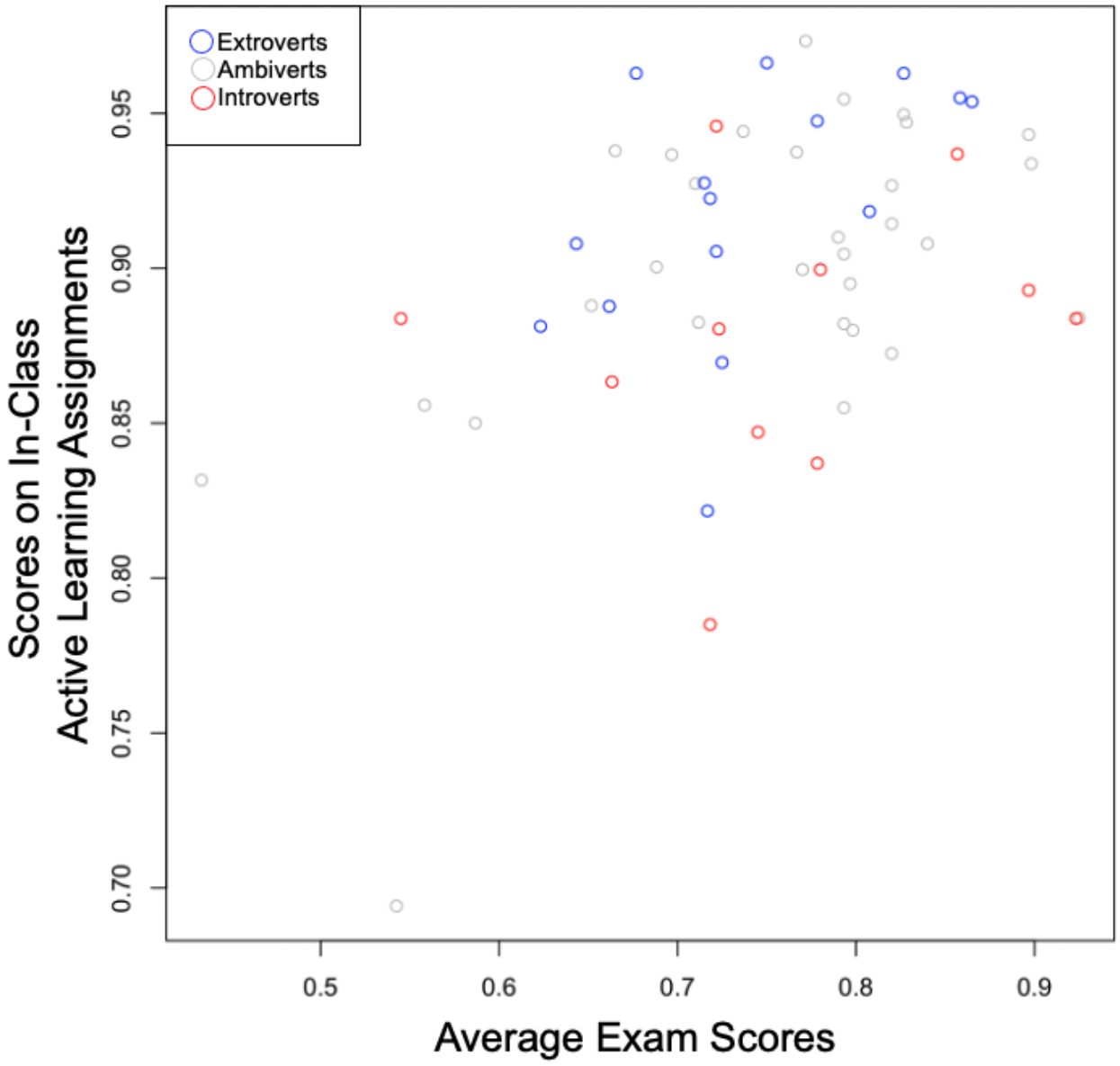

Figure 3. Dot plot demonstrating the relationship between exam performance, x-axis, and performance on the in-class, group-oriented active learning assignments, y-axis. Red circles represent students who scored as introverts on the IPIP test for extraversion, while grey circles represent students who scored as ambiverts and blue circles represent students that scored as extroverts.

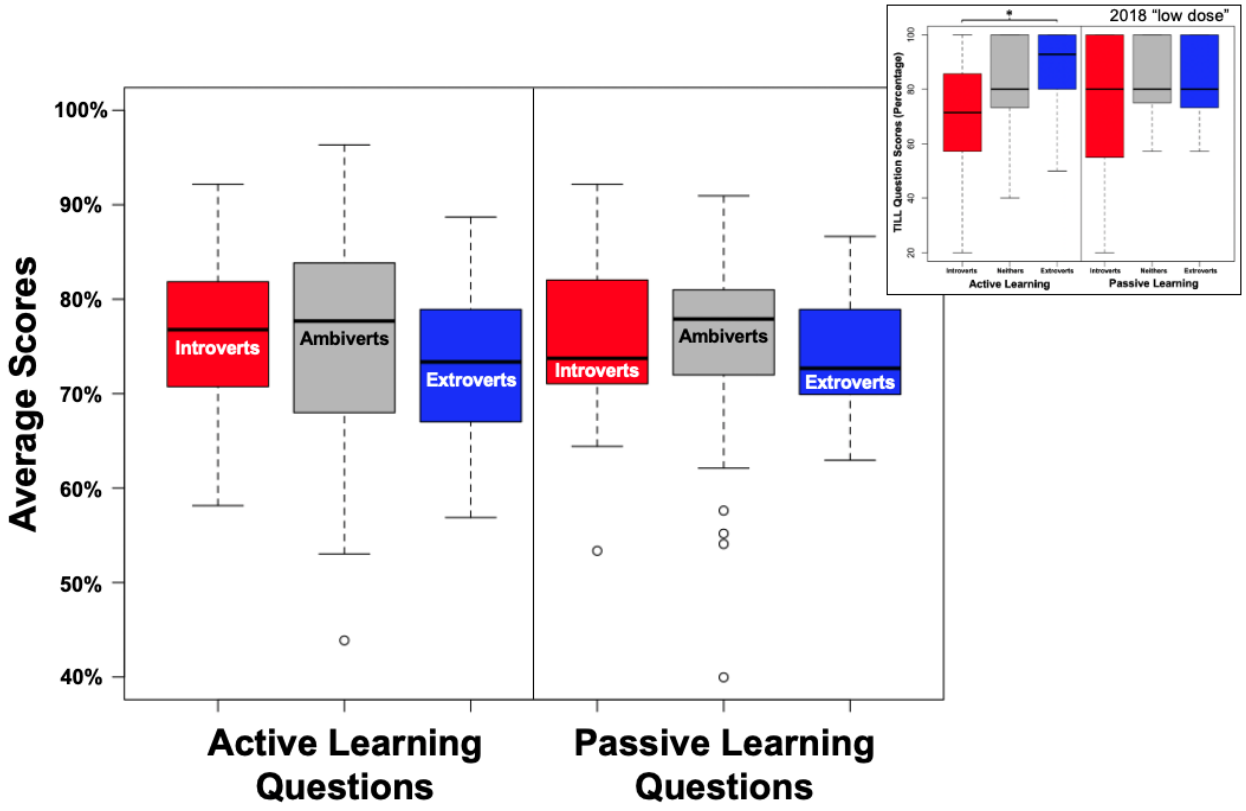

Figure 4. Distribution of average exam scores across all 4 exams, separated by questions pertaining to material delivered by either active learning group exercises or passive learning lecture-style teaching, across all three social personality types. Box and whisker plots represent the quartiles for participants with statistical outliers shown as open circles and the group median scores shown with bold black lines. The large figure represents the "High Dose" dissemination of active learning, with eight total group-oriented active learning lectures and the entire class being conducted in the active learning session, while the smaller figure in the upper right demonstrates the results from Beckerson et al., 2020 as a "Low Dose" comparison where only two total group-oriented active learning activities were held in an active learning setting for each participant and the remainder of lecture material was disseminated via passive learning styles in a traditional lecture hall setting. Type III analysis of variance with Satterthwaite's methods showed no

statistical significance ($F_{2,55}$ = 3.93e-1, p = 6.75e-1, ns) in the "High Dose" comparison between active/passive learning question performance with regards to personality types while the "Low Dose" study showed a significant effect ($F_{2,32}$ = 3.16, p = 3.10e-2) .

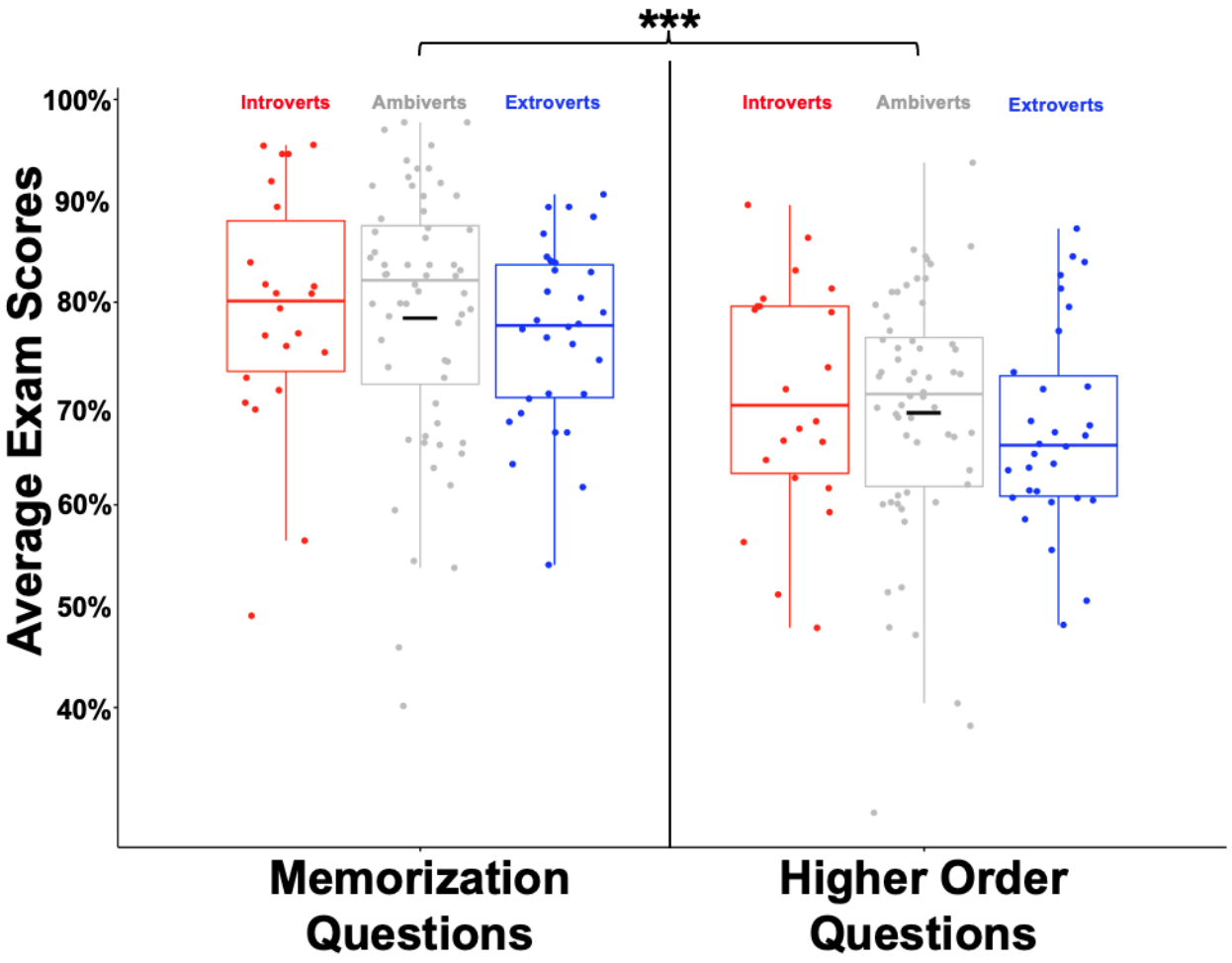

Figure 5. Distribution of average exam scores, separated by questions type, across all three social personality types. Box and whisker plots represent the quartiles for participants with median scores shown as bold lines colored according to group. Centered bold black lines represent the averages for all personality types. Type III analysis of variance with Satterthwaite's methods showed a statistically significant difference between overall performance on memorization question and

higher order question ($F_{1,55}$ = 35.67, p = 4.09e-3), but no significant difference with regards to personality type $F_{2,55}$ = 1.46 e-1, p = 8.64e-1).

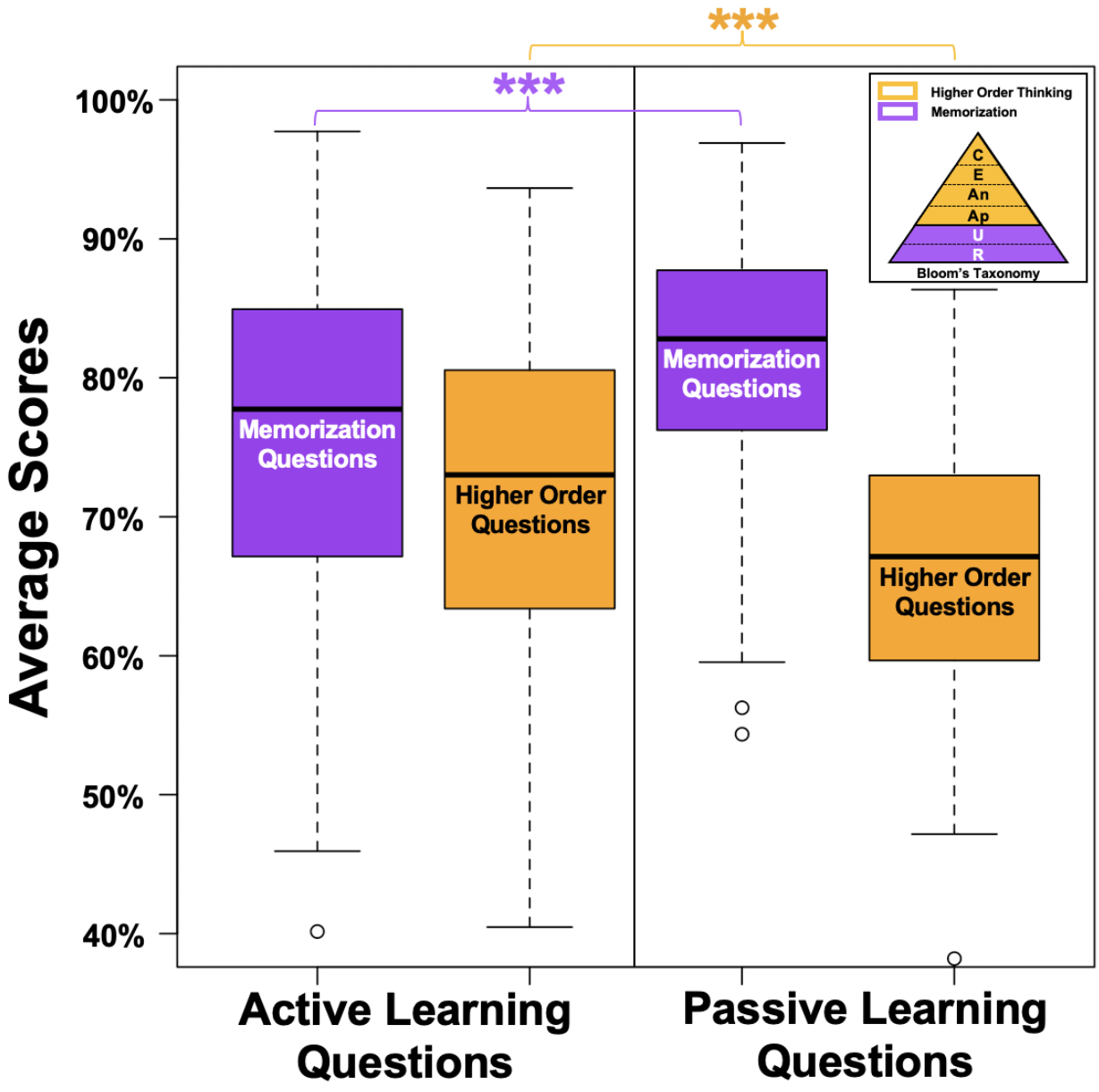

Figure 6. Distribution of average exam scores, separated by questions type and lecture style. Memorization questions are defined as the bottom two tiers of Bloom's Taxonomy, top right, while Higher-order questions are defined as the top four tiers. Box and whisker plots represent the

quartiles for participants with statistical outliers shown as open circles below the plots and the group median scores shown with bold black lines. Type III Analysis of variance with Satterthwaite's methods were used to test for significance between lecture style, exam scores, and question type ($F_{1,55}$ = 51.07, p = 2.55e-12). The purple brackets and stars indicate statistical difference in performance on memorization questions between lecture styles ($F_{1,55}$ = 16.00, p = 7.60e-5), and the orange bracket and stars indicate statistical difference in performance on higher-order questions between lecture styles ($F_{1,55}$ = 27.745, p = 2.29e-7).

Table 1. Data classification for this study

Variable Name	**Subcategories**	**Data Classification/Type**	**Effect Type**
Social Personality	Introvert, Ambivert, Extrovert	Categorical/Ordinal	Fixed
Group ID	1-11	Categorical/Ordinal	Random
Exams	1-4	Categorical/Ordinal	Random
Learning Type	Active, Passive	Categorical/Binomial	Fixed
Question Type	Higher Order, Memorization	Categorical/Binomial	Fixed
Average Exam Scores	[0%, 100%]	Numerical/Continuous	Response
Active Learning Questions Scores	[0%, 100%]	Numerical/Continuous	Response
Passive Learning Questions Scores	[0%, 100%]	Numerical/Continuous	Response

Active Learning Higher Order Questions Scores	[0%, 100%]	Numerical/Continuous	Response
Active Learning Memorization Questions Scores	[0%, 100%]	Numerical/Continuous	Response
Passive Learning Higher Order Questions Scores	[0%, 100%]	Numerical/Continuous	Response
Passive Learning Memorization Questions Scores	[0%, 100%]	Numerical/Continuous	Response

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