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Evaluation of the redesign of a STEM gatekeeper course, General Chemistry I, incorporating active-learning strategies and implementation of a student-choice model

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EVALUATION OF THE REDESIGN OF A STEM GATEKEEPER COURSE, GENERAL CHEMISTRY I, INCORPORATING ACTIVE-LEARNING STRATEGIES AND IMPLEMENTATION OF A STUDENT-CHOICE MODEL

by

TRAVIS RAE MCDOWELL

A DISSERTATION

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In Partial Fulfillment of the Requirements for the Degree

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ABSTRACT

The first courses freshman university students typically enroll in are the introductory science and math, courses that bridge from and build upon their prior educational experiences. These introductory courses often have large enrollment lectures coupled with supplemental sessions to teach using traditional educational practices, which may operate counter to the attitudes and culture of the students who take them. To address this, the general chemistry faculty through collaboration with a team of educational specialists initiated a redesign of the general chemistry course, which primarily serves first-year undergraduates. The redesign efforts included changes such as reducing lecture time and placing emphasis on increased time spent in the more student-centered recitation sections in addition to the generation of online course participation options geared towards students that are more independent. This redesign of a first-year general chemistry course offers useful insights and guidance towards redesigning other similar science, technology, engineering, and math (STEM) courses.

This dissertation describes efforts to redesign the general chemistry gatekeeper course at Missouri University of Science and Technology (Missouri S&T) through the implementation of a student-choice model allowing students to choose a course participation option that best suits their learning needs. Student performance in multiple grade categories was analyzed using statistical methods to determine the influence of changes throughout the redesign. The findings from this study indicated that the student-choice model was successful in achieving goals of improving course efficiency and increasing student accommodation with no detriment to student performance.

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1. INTRODUCTION

1.1. THE CURRENT EDUCATIONAL LANDSCAPE

Each year students enter the college environment with the goal of earning a degree in a field of their interest, which will ultimately lead to a career. While the general goals of each new cohort of students has remained relatively consistent, the culture that has forged their attitudes and habits has undergone continual change [1, 2]. For most present-day students, the cultural shift they have experienced relates to the availability and accessibility of information. Information once only localized to specific sources such as books or direct instruction now competes with information and digital media made easily accessible due to the rapid improvement and proliferation of internet technologies [1, 2, 3]. This constant access has changed the way students find answers to their questions and interact socially with one another. Now, instead of poring through books to find information or directly discussing a problem with an instructor, students consult Google, YouTube, and other online resources to find answers to their questions [1, 2, 3, 4, 5, 6, 7, 8, 9].

Because of these changes to the culture of learning, it is imperative to rethink the efficacy of instructional methods that have been traditionally used. Are the traditional methods still the best approach? If not, what changes should be made to better align with the current student culture and the new technologies that surround them [2, 4, 8, 10, 11]? These are especially pertinent questions within the constantly growing fields of science, technology, engineering, and math (STEM) where up to date information and technology usage are often key aspects of the curricula [11, 12, 13]. While traditional methods of instruction through the use of lectures and recitations has had success, current and especially future students may not benefit as strongly from them as has occurred in the past [2, 4, 6, 8, 14]. It is also possible that, without changes, traditional instructional methods may have lower success to a student culture that increasingly takes instant access to information through online access to resources for granted [2, 4, 8, 14]. In addition to the possible academic shortcomings, practical issues pertaining to infrastructure, space, personnel, etc., are of concern as the number of new students enrolling in college is projected to increase over the next decade [15, 16].

1.2. TRADITIONAL INSTRUCTIONAL METHODS

To determine how best to improve the tools of education for the present-day student, it is first necessary to be familiar with the methods that have persisted over the years, why they are used, and the criticisms directed at them. The methods which will be discussed include the use of traditional lecture, recitation, and student success programs with a focus on how they relate to first year (freshman) and second year (sophomore) college students within STEM focused courses. Additionally, with any focus on large, freshman-level courses it is necessary to discuss the concept and intent of a gatekeeper course.

1.2.1 Gatekeeper Courses. Gatekeeper courses are generally considered as the introductory level courses in math, science, English, etc. These courses are meant to be completed within the first year of college entrance and are taken mostly by students who are not majoring in the specific subject [17, 18]. The general purpose of gatekeeper courses is to help develop basic skills that many students lack, but which are considered necessary for success within the greater college environment [19, 20, 21]. The basic skills in need of development can range from academic deficiencies related to the technical aspects of the course soft skills such as communication ability, critical thinking, and problem solving which are highly desired by employers and more difficult to quantify [19, 24, 25, 26].

Due to the often-large number of new students enrolling each academic year, gatekeeper courses often have the largest class sizes of any course at a university [17, 18]. To accommodate the large number of students, these courses often utilize large lectures (> 100 students) which are supplemented by recitation sessions [17, 18, 22]. For freshman students enrolling in these courses, it is also often necessary to offer further assistance either through various student success programs or remedial courses [17, 23, 27, 28, 29, 30, 31].

1.2.2 Traditional Lecture. Throughout the majority of their educational experience, most students are primarily instructed through traditional lectures [32, 33, 34]. The general idea of a lecture, which has undergone little change throughout the years, involves a knowledgeable instructor or expert in a field of study delivering an oral presentation to a group who has less knowledge of the subject material. Instructors usually stand to the front conveying topic-specific information to students who typically are trying to take detailed notes while attempting to follow along with the information as it is delivered [33, 34, 35].

Lectures have experienced few changes over the years, beyond those that are arguably superficial in nature. In more modern times lecturers use digital presentations to visually present information as opposed to the use of a chalkboard or reading from written lecture notes. To move towards a more active climate, lectures have incorporated personal response devices (clickers) for digital polling of topics as these topics are introduced and discussed [36, 37, 38, 39]. In spite of these changes, lectures have remained consistent in nature, with an instructor conveying information to a waiting classroom of learners [14, 22, 40]. Instructors often maintain affinity for lectures for a variety of reasons. Lectures are relatively simple to prepare and a highly familiar instructional tool for most instructors and students. Additionally, lectures offer instructors an apparent control of the classroom and the information delivery process [22, 40]. Despite these reasons, the continued use of lectures as a primary instructional tool is not without criticisms. While lectures would appear to be engaging from the instructor's perspective, it is generally a one-way method of communication; instructors speak while students listen and take notes. Even with the addition of digital polling, lectures typically remain a highly passive instructional method. Even in courses with a highly engaging instructor, it can be difficult to maintain student focus on the presented material [33, 34]. For larger courses or gatekeeper courses, taken primarily by non-major students, the negative effects of the traditional lecture can increase. Larger courses increase the difficulty of having any back-and-forth communication, rendering lectures nearly completely passive [3, 17, 35, 41]. Non-major freshman, being new to the college environment often have no prior experiences with large lecture courses. This lack of familiarity can result in further difficulties they experience due to any incoming skill deficiencies they may have, or due to the apprehension that they may have with asking questions [41]. Current students also experience added distractions in the form of the technology they consistently carry such as smart phones, tablets, and laptops [3, 4, 8, 42, 43].

1.2.3 Recitation. To supplement lectures, especially for larger courses and gatekeeper courses, recitations are often used [22, 44]. The general purpose of recitation is to provide a time for discussion over pertinent topics or examine example problems with explanations that may have been prohibitively difficult during the lecture. Recitation sessions are most often led by a graduate teaching assistant (GTA), with each session being attended by only a small group of the students in the course (25-30 students). This smaller class size has the potential to create a more comfortable setting encouraging active discussion between the students and recitation instructor, which is not always possible during the lecture [22, 44]. Students may also experience greater ease discussing topics with a GTA rather than with the instructor, as they perceive the GTA more like a peer [45, 46].

While recitation sessions are a highly useful instructional tool due to their smaller class sizes, they also have issues that need to be considered. Due to the GTAs' familiarity with receiving information via a traditional lecture format, recitations can often devolve into just that, another lecture. When using the traditional lecture format recitations become a lost opportunity for the promotion of active learning and collaborative problem solving. This can be detrimental to many students who need assistance that would be easily accomplished through the discussion and practice a recitation is intended to offer. In the case of large enrollment courses, multiple recitation sections are necessary to accommodate all the students in the course, which can require the use of multiple GTAs who may have varying ability both in knowledge of the material and their presentation skills. These variations in ability can lead to reduced consistency in the messages conveyed and students' learning experience [34, 47].

1.2.4 Student Success Programs. A final method by which a course can attempt to assist students is through remediation and practice, often achieved through implementation of various student success programs. These programs can be mandatory or voluntary, peer-led or instructor led, and can be associated with the campus at large or be tailored to individual courses [19, 20, 30, 31, 48]. Student success programs are often more prevalent as freshman programs due to the generally high variance in academic skill level of incoming freshman [19, 20, 21, 31, 48]. These programs generally serve to assist students in developing best practices regarding their academic success. Most student success programs, especially when tailored to a particular topic or course, involve some aspect of remediation through practice over basic concepts [30, 48]. The use of student success programs have grown in popularity as ways of increasing retention among incoming students and improving student skills so they can maintain academic success [19, 20, 21, 30, 31, 48, 52]. Student success programs often rely on undergraduate learning assistants (ULAs), students who have been successful either at the university level or within a given course, to promote collaborative learning and provide a boost to the social framework of newer students [31, 48, 49, 50]. While student success programs have shown successes in improving student outcomes, on their own they are not enough to maintain success in college [19, 20, 31].

1.3. ALTERNATIVE EDUCATIONAL STRATEGIES

Due to the issues faced within the traditional methods listed, many alternative educational strategies have been developed. A key aim of these strategies is not to “reinvent the wheel” but to improve upon the ideas that have come before. Behind many of these learning strategies is a desire to more effectively use the available resources to support the development of student with diverse academic skill levels [19, 20, 21]. In addition to improving content knowledge, another aim of these alternative strategies is to offer more opportunities for the development of important soft skills (e.g. problem solving, critical thinking) which contribute to making students more successful and, ideally, more employable upon their graduation [24, 25, 26]. These educational strategies are often used with freshman students or alongside gatekeeper courses, with the purpose of improving retention through remediation or preparation. Additionally, it is common to use peer learning, either through emphasis of student-student collaboration, or by the addition of ULAs [30, 53]. Implementation of these strategies is generally need-dependent and it is common for multiple approaches to be utilized together to magnify their benefits and reach a greater number of students [50].

1.3.1 Freshman Programs. As stated, many of the educational strategies employed are directly focused on improving preparation and retention among freshman students. This focus is generated by multiple factors that tend to influence freshman primarily. These factors can include low preparedness of incoming students within a given subject material or social issues caused by feelings of isolation. These issues can often increase for large gatekeeper courses and STEM courses where students may feel a lack of support or be in need of remediation to get at a level where success can be achieved [19, 20, 50]. To combat these issues many universities offer transitional assistance in the form of First Year Experience Programs (FYEPs).

These programs generally focus heavily on the social needs of first year students who, upon coming to the university, often need to build new social connections. FYEPs can be mandatory or optional, but often serve as an additional course starting at orientation [19, 20]. Students enrolled in these programs are often assigned to an upperclassmen peer leader who leads the group. These groups, which are generally formed around common personal or academic interests, can serve similar to clubs helping students meet other students [48, 50]. It is also common for students in these programs to be engaged in instructional tasks focusing on improving needed soft skills such as time management, interpersonal communication, and study skills so that they can be more successful at the university [24, 25, 26].

An analysis of the results for these programs generally showed mixed to positive results. Data from multiple studies indicate a generally positive improvement towards student retention. Students in these programs also indicated a more positive opinion of their experiences within the first year [20, 30, 31, 51, 52]. While students within these programs tend to have more positive outlooks and increased retention, other data indicate a more mixed message as the gains in student performance often failed to be significantly higher [51, 52]. This would indicate that FYEPs are valuable for retaining students but not necessarily for improving student outcomes.

1.3.2 Supplemental Instruction. While FYEPs indicated some positive outcomes towards retention, it is also important to generate strong foundational knowledge and improve students' learning outcomes in individual subjects. To accomplish this goal, alternative strategies such as Supplemental Instruction (SI) and Process Oriented Guided Inquiry Learning (POGIL) have been developed. SI is a strategy developed at the University of Missouri-Kansas City and "provides regularly scheduled review sessions on course materials outside the classroom. SI study sessions are informal seminars in which students compare notes, discuss readings, predict test items and develop tools for effective organization" [54, 55, 56]. SI is commonly used in courses where students traditionally encounter more difficulty such as STEM and gatekeeper courses, but can be used in conjunction with any course as needed. SI is geared towards voluntary attendance and peer assistants who have shown aptitude within a course are used in SI to help students develop the skills necessary for academic success [30, 54, 55, 56].

While different SI programs have had varying levels of success, implemented SI programs have overall shown positive outcomes. Participating students had higher retention than non-participants as well as improved learning outcomes. This strategy, while not considered remedial, can act as a remediation for some students who fall behind. Additionally, the study sessions encourage student interaction, which ultimately can lead to the development of needed social connections [30, 54, 55].

1.3.3 Process Oriented Guided Inquiry Learning. Similar to the previous strategies, POGIL is focused on promoting student-student interactions through the formation of groups. As a strategy, POGIL works through the formation of small groups, generally 3-4 students, who work together on assigned problems with the goal of developing a conceptual understanding of presented material. Of key importance is the assignment of roles to each member of the group to explore different concepts while the instructor serves as a moderator when necessary [57, 58]. The goals of this strategy, like other strategies, is to use collaborative learning to develop a better comprehension of given course material. As the instructor takes a more "hands-off" role in facilitating active collaboration, the POGIL strategy is expected to lead to a greater and longer-lasting understanding of discussed material [57, 58]. This strategy is designed to be employed during a class session, but can be readily adapted for use in voluntary study sessions [57, 58].

As with other active and collaborative learning focused strategies, POGIL has been shown to be successful. Students in courses using POGIL showed improved content knowledge, and had higher retention than students instructed solely through traditional means. Students surveyed after experiencing POGIL indicated a preference for the method over traditional instructional methods. POGIL is a more recently developed model with a focus on chemistry courses and there are only limited studies outside of chemistry courses, though preliminary results have been positive [57, 58].

1.3.4 Peer-Led Team Learning. Another instructional strategy, which shares similarities with POGIL and SI, is Peer-Led Team Learning (PLTL). PLTL places students into groups of 6 to 8 to collaborate on solving problems using all available resources in a workshop style session. Each collaborative group is facilitated by a peer leader who has successfully completed the course, generally with a grade of *B* or higher. Peer leaders interact with the group members through leading questions in a similar fashion as that used in POGIL. While PLTL sessions can be generated as additional voluntary sessions, typically they are incorporated into a course as a mandatory part of the course [59, 60]. Implementation of PLTL session as a mandatory course meeting is typically accomplished through a reduction in lecture time so that this special session can be held. Students involved in PLTL sessions tended towards small, but significant increases in performance with data suggesting noticeable increases in critical thinking skills [59, 60].

1.3.5 Undergraduate Learning Assistants. One commonality between many of the aforementioned strategies is a reliance on ULAs. Peer-assisted learning strategies, while not a completely new idea, has become more widespread making it an important topic of discussion. Typically, peer-assisted learning strategies utilize ULAs that act as a bridge between students and instructors. Requirements for becoming a peer-assistant vary by university, with the only constant being that an assistant must have previously participated in and been successful in a course or program in a previous semester [53, 61].

Peer-assistants are beneficial as mentors and role models for students who may be intimidated by the new environment that college presents. Due to their prior experience and success in a course or at the university, they can be invaluable at introducing new students to positive study methods in addition to assisting with questions students may not wish to ask directly the faculty or graduate teaching assistants. Peer-assistants can also be a highly useful resource in larger gatekeeper courses where instructor-student interactions can be more difficult to achieve due to the high student-teacher ratio [53, 60].

1.3.6 Technology Enhancement. In addition to the socially based education strategies discussed previously, it has become a necessity for courses to modernize and implement some level of technology-enhancement. Technology tools can also be necessary due to the characteristics of current students who prioritize online resources over physical ones. A technology-enhancement can be as simple as employing a Learning Management System (LMS) as a primary location for sharing course resources, informing students of course-related events, and allowing students to track their grades. Additionally, LMS's have begun to become primary locations for course assignments. Online assignments can lead to an ease of the grading burden on an instructor through automation, while providing more instantaneous feedback to students and improved consistency in the grading process [14, 62]. Additionally, many online programs allow for randomized questions, which can be useful in pressuring students to learn a concept rather than copying another student's answers.

Another technology-enhancement is the addition of personal response devices and direct polling in lecture courses, taking advantage of a culture of learners who have a high familiarity with and tendency to utilize some form of a mobile device [3, 6, 14, 42, 43]. As stated previously, lectures are generally passive learning experiences. The addition of interactive polling via personal response devices provide both on-time feedback to students and allows the instructor to receive instantaneous feedback about the level of students' understanding of the topic discussed during lecture. This strategy not only offers a look into how well students are grasping the material, but also provides opportunities for further discussions and improvisation in large classes, where active experiences are more difficult [36, 38, 39].

Other technological course enhancements include the implementation of online discussion boards, live-chats, and other online forums, which can be used to provide answers to students as opposed to using email or relying on limited office hours. These online forums can also promote student-student discussion by providing students with the opportunity to pose questions to, and answer the questions of other students within a course. Some students may even use these forums to coordinate face-to-face study sessions with one another [63, 64].

Finally, virtual classrooms are also becoming an increasingly popular option for synchronously, or asynchronously delivering course material and interacting with students without the need to be in the same physical location. For STEM courses that rely on lab experiences as part of their curricula, virtual labs can be a viable option for many universities. Virtual labs can allow students to experience a lab while at the same time saving space and resources for the university. The benefits of virtual classroom experiences while generally more focused towards distance students, in some instances have become a regular aspect of some courses [65, 66].

1.3.7 Hybrid/Blended Learning. As technology and web-enhancements have become more commonplace within classroom environments, strategies that blend online and face-to-face (F2F) experiences have become more popular. Blended, or hybrid courses use increased levels of web-enhancement in combination with F2F experiences as part of their teaching mission. Due to the increased use of digital tools in higher education, most modern courses are arguably blended to varying degrees of effectiveness. The ideal goal of a blended course, like with many of the instructional strategies presented, is to make the teaching and learning processes more student-focused [2, 3, 4, 67]. This is accomplished by using the digital tools that allow students to work on their own, which in turn allows the instructor to offer a more individualized F2F experience for students [3, 4, 11, 40, 67].

In addition to an attempt to make a course more student-centered, blended learning can also be useful from an administrative standpoint. By offering parts of the course within the digital space, physical space on a university can be freed up. This movement to a digital space also allows an instructor to deliver the course to more students than would be possible in a typical course relying only on traditional means, which can free up instructors to teach other courses. While still a newer strategy that is still to be fully investigated, blended learning has been shown to have higher student outcomes over fully F2F and fully online methods [1, 2, 4, 67, 70]. A part of the success of blended learning can be attributed to the characteristics of current students, for whom internet-technologies have consistently been a part of their entire lives.

1.4. GENERAL CHEMISTRY AT MISSOURI S&T

This dissertation will cover the efforts to modernize the general chemistry experience through a course redesign at Missouri University of Science and Technology (Missouri S&T). The redesign incorporated key aspects of the various strategies discussed above. A major part of the redesign was the inclusion of increased opportunities for active and collaborative learning with a goal of improving student learning outcomes. As a gatekeeper course serving primarily non-major students, it was also intended that the redesign would have an impact on developing skills that would have a lasting effect throughout students’ time at the university. In addition to improvement in student learning outcomes, the redesign took into account the increasing enrollment without an accompanying increase in space and personnel; the proposed solution was the inclusion of available online options for lecture and recitation. The availability of both F2F and online options allowed students to tailor their educational experience in a way that best served their individual needs.

Prior to the course re-redesign, student outcomes for General Chemistry I, the gatekeeper course that is the focus of this dissertation, were achieved primarily through traditional methods which included instructor-led F2F three times per week accompanied by one GTA-led 50 minute recitation session each week. The course also used an LMS [68], an online homework system [69], and personal response device polling (Turning Technologies) implemented during lecture sessions. The course had 4 separate lecture sessions and 32 recitation sections to accommodate approximately 750 students. This system accounted for four weekly contact hours for each student. Workload for the course was divided between three to four research professors acting as primary lecturers, and approximately eight to nine GTAs who handled the bulk of grading along with leading the recitation sessions. In addition to individual office hours provided by the instructors and GTAs, the course had instructor-driven and peer-assisted help sessions offered four times per week that increased the available contact hours by an additional 8 hours. These *optional help sessions* were offered via the Learning Enhancement Across Disciplines (LEAD) program and were generally used by students as an opportunity to complete homework with instructor and peer-assistance [72].

1.4.1 Lecture and Recitation. Efforts to redesign the lecture and recitation included shifting emphasis from the lecture portion of the course to the recitation. This included changing F2F recitations from their traditional role as a supplemental lecture into a more active, collaborative problem-solving session. As a major component of the redesign, the course underwent an infrastructure change that included the addition of online sections for lecture and recitation. In addition to these new options, students were given a choice in which way they preferred in their educational experience between fully F2F, blended F2F and online, or fully online. This changed to the infrastructure of the course also gave the opportunity to improve efficiency of available resources such as space and personnel.

1.4.2 Learning Enhancement Across Disciplines. Another facet of redesign included adjustments to the operation of the LEAD sessions. Initially, LEAD for general chemistry at Missouri S&T served as an opportunity for students and instructors to interact outside of office hours with a focus on aiding students with the understanding of the concepts in the course. Prior to redesign, LEAD was used by students primarily as a time to complete homework without focus on student-student interaction while in the proximity of an instructor and peer-assistant. The redesign of the LEAD sessions focused on converting these sessions into an active-learning environment. Tenets of SI, POGIL, and PLTL were integrated into LEAD sessions to generate peer discussion and collaboration during the problem solving sessions. Instructors and ULAs provide moderation and need-based guidance to make LEAD sessions more student-centered. These changes were drove by the addition of practice problems at varying difficulty levels, providing an opportunity for students to practice the major concepts in the course beyond their assigned homework. The implementation of these changes allowed students to spend more time-on-task with course content in an environment conducive to building soft skills such as collaboration and communication.

2. LECTURE REDESIGN DURING FALL GENERAL CHEMISTRY

2.1. LECTURE AS INSTRUCTIONAL STRATEGY

The primary purpose of a lecture session is the direct delivery of information from an instructor to a group of students. The primary method of this information delivery involves an oral presentation of information with supplemental help in the form of slides, sketches, definitions, and examples. While lectures have been a mainstay of the academic experience for many years, they have been the focus of criticisms regarding their effectiveness for nearly as long. Lecture critics tend to have a major focus on its passive, instructor-centered nature. Lectures generally operate on the assumption that the instructor is not only an expert in the field they are discussing, but also an persuasive speaker capable of effectively translating and subsequently disseminating given information in an easy to understand manner. Additionally, successful lectures require students to maintain a relatively long engagement, generally an hour or more, and not only absorb but also comprehend the information being conveyed to them [36, 39, 74]. Put another way, for a lecture to be successful there are a multitude of factors that need to be satisfied by both the instructor and the students involved in it.

The persistence of lectures as a primary instructional tool is often attributed to the simplicity of their deployment, even when used under non-optimum conditions such is the case with gatekeeper courses that have large student populations consisting primarily of non-majors. That is, presentation of course content having a strong emphasis on technical material that is important to student majors, but lacking in importance for non-majors, can leave non-major students feeling lost or indifferent toward the course material or the course itself. Larger class sizes can minimize student-instructor and student-student communication opportunities. Additionally, many incoming freshman have never been a part of classes larger than 30 of their peers. The effect of being suddenly thrust into such large classes, in a new environment and without the needed social scaffolding they experienced during their pre-college experience can be highly intimidating [49, 75]. The interaction of these factors within a typical gatekeeper course can lead students to disconnects that are difficult to overcome.

An additional difficulty with the use of traditional lectures as a primary instructional method relates to changing student attitudes and expectations pertaining to technology in the classroom. Most current students have experienced a life where any information has been available to them upon demand. This can lead to difficulty with maintaining student attention, especially during a large lecture where distractions can be harder to notice [1, 2, 5]. In smaller classes, it is possible for an instructor to monitor and control technology usage and minimize distractions. In larger courses, minimizing distractions caused by errant technology usage and successfully conducting the lecture can be prohibitively difficult. Additionally, with the thought that any missed information can be worked out later on their own time, many students can find lecture to be a tedious undertaking that does not effectively fit with their ideas of learning [1, 2, 3, 4, 74].

Despite the fact that these criticisms have persisted and are generally well known by most instructors, it has been difficult for alternative methods to gain traction. Some instructors are apprehensive to change due to having become familiar with this method of instruction through first-hand experience during their own education. For other instructors, it is difficult to let go of the influence they perceive themselves as having in their role as a primary lecturer. Additionally, innovations to improve upon the traditional lecture format can be further limited due to the general simplicity of utilizing a traditional lecture format and an instructor’s preference to conduct lectures using an already established, approved, and peer-understood instructional tool [22, 40].

While large-scale alternatives have been exceedingly rare, improvements to technology have allowed incremental changes to the traditional lecture format to occur. For example, the use of digital, shareable presentations gave students direct access to the instructor notes [62, 74]. This strategy can minimize note-taking errors for students unable to keep up with the typical note-taking pace of a lecture. On the other hand, to gauge student understanding of course material, direct electronic polling has become increasingly commonplace in larger lectures. Utilizing class polling during the lecture time also has the potential to improve students’ engagement, as they have to maintain an active focus on the lecture presentation to answer successfully the given questions. While these changes would appear to be positive additions to traditional lectures, they have had inconsistent results towards promoting higher engagement and improved course performance [36, 38, 39].

2.2. GENERAL CHEMISTRY FALL COURSE AT MISSOURI S&T

General Chemistry I (previously CHEM 1, currently CHEM 1310) at Missouri S&T is a typical gatekeeper style course. As represented in Figure 2.1, freshman students within one of their first two semesters make up the bulk of the enrolled course population, with only about 20% of students taking the course at later points in their educational career either due to a delay of taking the course or to fill a need after transferring to the university.

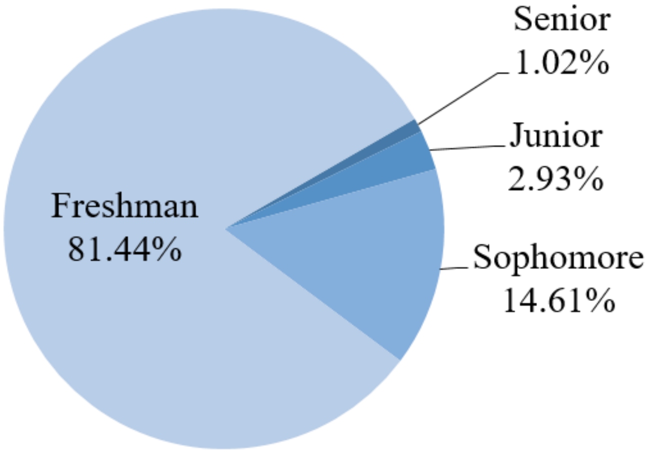


Figure 2.1. Academic level of students enrolled in fall semester CHEM 1310 from 2010 - 2016

Of those students enrolled in general chemistry, the population is comprised heavily of students declared as non-major students heavily comprise the population, while less than 16% of students are enrolled in chemistry intensive majors which includes biology, biological engineering, chemical engineering, and physics, as shown in Figure 2.2.

To accommodate the large number of students, the Fall semester of the course was divided into 4 main lecture sections each led by a different instructor. Each section seated 180 – 200 students who met for three, one-hour lecture sessions per week. The course was supplemented by one-hour GTA-led recitation sessions which students attended once per week. Students could voluntarily attend the instructor-led student success sessions through the LEAD program which were available four evenings per week [86].

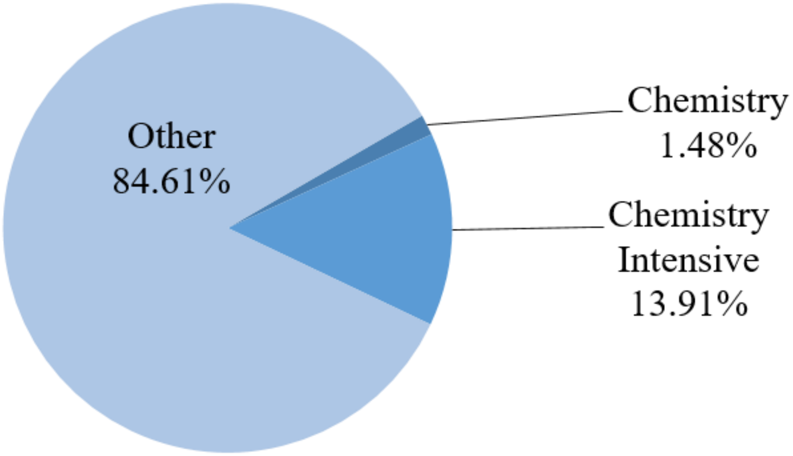


Figure 2.2. Majors of students enrolled in fall semester CHEM 1310 from 2010 – 2016

Starting in 2004, general chemistry began to undergo changes meant to homogenize the course experience for students and begin to promote some active-learning strategies. A major change was the aligning of the four sections which were initially taught independently of one another so that the course experience for all enrolled students would be more similar. Aligning the course was done by generation of a common syllabus and use of the same assignments and exams across all general chemistry sections. Course management was accomplished through an online learning management system (LMS) which primarily gave students a common location to access course files and grades. To promote a more active learning environment, personal response devices along with digital, real-time polling was instituted. Additionally, students were encouraged to read the text and create reading notes that were collected randomly several times throughout the semester [86].

To reduce the considerable workload and improve consistency related to the grading of homework assignments, an online homework delivery system was integrated into the course in 2006. The online homework system automatically graded the assignments and provided instant feedback to students, a significant departure from the previous method of homework assignments that were submitted on paper and later graded by instructors and GTAs in the course [86].

Along with an increase in online resources, the use of a common course discussion board began in 2007. The discussion board, which was operated within the course LMS, gave students a place to ask questions about course topics, communicate with instructors and GTAs, and interact with other students in the course [86].

In 2009, the grading workload was further reduced replacing the randomly collected reading notes with reading quizzes assigned through the online homework system. The change to online reading quizzes was meant to improve student preparation for upcoming lectures. The change, similar to the homework changes made in 2006, were intended to reduce the GTA grading load and further improve consistency of grading[86].

These changes to the course improved grading consistency, generated instantaneous feedback, and modernized the course strategies. These changes were all considered beneficial to student engagement and improved student outcomes. While these modifications had effects that could help students, the general focus of the improvements implemented prior to the major course redesign starting in 2011 were primarily focused on reducing the workloads of instructors and GTAs [86].

2.3. REDESIGN OF GENERAL CHEMISTRY FALL COURSE AT MISSOURI S&T

In 2011, a major course redesign initiative was started by the Governor of Missouri in collaboration with Missouri’s 13 public four-year institutions of higher education and in partnership with the National Center for Academic Transformation [82]. The initiative had the purpose of redesigning large-enrollment multi-section courses with technology-supported active learning strategies. Missouri S&T participated in this initiative to address the following academic issues with CHEM 1310:

- Different chemistry backgrounds: about 10% of enrolled students had no previous chemistry course, whereas 20% had AP chemistry or college-level introductory chemistry.
- Poor study skills: students relied too much on rote memorization rather than developing conceptual thinking and problem-solving skills.
- Lack of active learning: recitations served as additional lectures without opportunities for active learning and higher-order thinking instructional tasks
- Reduction of instructional personnel: the department lost several faculty positions due to academic hiring-freeze policies.
- Limitation of classroom space: enrollment continued to increase without a corresponding increase in classroom space.

The redesign initiative covered not only the lecture sessions, but also the recitations sessions which will be discussed in greater detail within section 3. Based on the problems stated, the lecture was redesigned to accomplish multiple goals. It was considered of highest importance that the redesigned lecture to create an increase in active-learning opportunities. Due to the limitations of large lecture courses for promoting these opportunities as well as the needs of the students who were primarily freshman and non-majors, it was decided that the lecture should be de-emphasized. By reducing the time spent in the highly passive lecture environment students would have more time in recitations, which were simultaneously becoming active-learning and collaborative problem-solving centers. During pre-redesign semesters, lectures covered one-hour sessions held three times per week while the recitation was a one-hour supplemental session held once per week, as shown in Figure 2.3. After course redesign, lectures were reduced to two one-hour sessions per week and recitation was increased to one two-hour sessions each week (see Figure 2.3) [86].

The change in the nature of the student experience meant that problem-solving practice would be shifted from the lecture, where it was often simply observed as worked examples completed by the instructor, to the recitations where examples were actively practiced by the students. This shift to more active problem-solving opportunities satisfied the needs of those students who could benefit from collaborative communication with their peers. While it was very important to make improvements to the learning experience of the students, there were still the issues related to classroom limitations and personnel availability [86].

The general chemistry course was already using the largest available lecture hall on campus and generally seated near capacity. With projected enrollment increases, classroom resources would only become further strained. While the addition of a fifth section was considered, there were multiple drawbacks including the need to further use the lecture hall that was already reserved much of the time. Additionally, this option would have degraded issues related to personnel, as another instructor and more GTAs would be required to handle the teaching load. This also would further limit the rather-thin resources for the instruction of higher level courses within the department. As an alternative to the addition of a fifth section, it was decided that online synchronous lecture sections could be an effective option. An online synchronous lecture allowed for a reduction in lecture sections in the fall from 4 to 2, as students could attend in real time the lecture from a location of their choosing without the need of being in the physical room where the F2F course took place. In addition to an online lecture option, an online recitation option was created. The available online options coupled with face-to-face (F2F) options became the basis of the redesign model utilized for CHEM 1310. The final major piece of the redesign model was the inclusion of student choice. Students were encouraged to enroll in the course options that best suited their individual needs allowing them a buffet of choices including F2F, online, or hybrids of the two [71, 82, 86].

The implementation of a student-choice model, with both online and face-to-face options, allowed for a reduction in the use of both personnel and space, but created secondary issues. The first issue was how to ensure that both lecture experiences, online and F2F, would be equivalent. The passive observation of lecture could easily be replicated through the use of a webcam, microphone, and online meeting program. While physical personal response devices would be ineffective outside of the lecture hall, an already existent application that made the personal response devices virtual allowed student access through an internet browser or smart phone application. The use of the online application combined with the use of synchronous online lectures allowed students, whether online or F2F, to experience the main active-learning aspect of the lectures. In addition, the ability to ask questions during class was replicated for the online students through the use of a chat client built into the meeting program. While students could not raise their hands, they would be able to discuss questions with any other student on the chat, which was further moderated by GTAs during the lecture session. These adjustments allowed for the synchronous online lecture to maintain a close equivalency to the experience of students within the physical lecture space with the only major difference being the location where students participate [86].

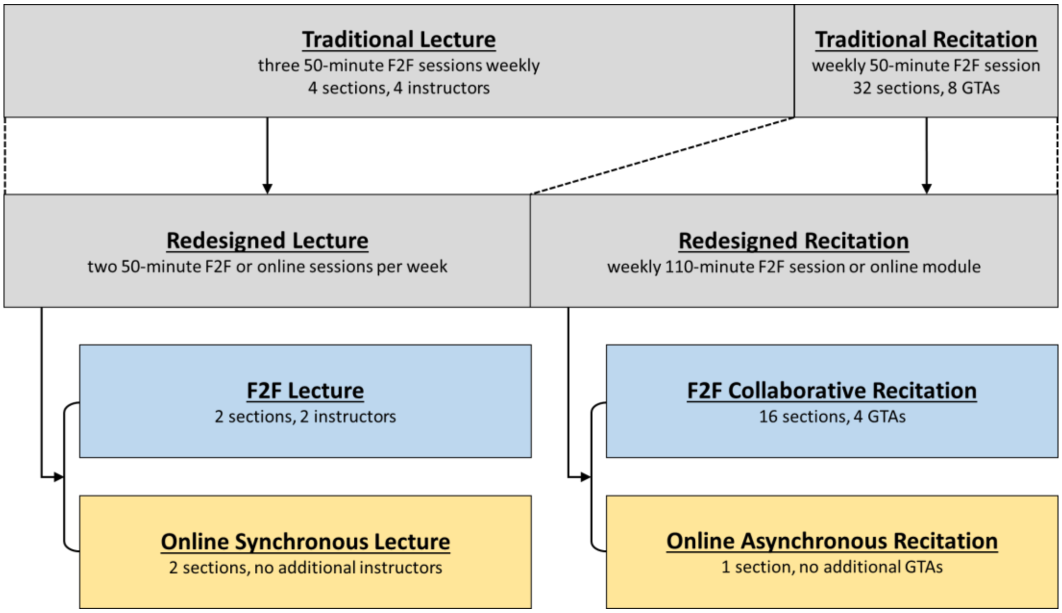


Figure 2.3. Redesign of CHEM 1310 from the traditional to the redesigned experience

A final issue with the student-choice model was the need to introduce students to the available online course options. Students had previously expressed dissatisfaction with other online course tools such as the course LMS, online homework system, and the course discussion board. Likewise, during the first enrollment period of the student-choice model, students expressed hesitation with choosing to experience the course via online course options. This initial hesitation led to the implementation of a mandatory, three-week sampling period during which all students would be required to experience both F2F and online options and thereafter make a more informed choice. At the end of the mandatory sampling period students would choose the course experience that they felt best suited them. As part of this student-choice model, if at a later point, after the mandatory sampling period, students desired to choose a different option they could, though most made their final determination at the end of the three weeks. These course options are represented in Figure 2.4 and include: A-F2F lecture and F2F recitation, B-online lecture and F2F recitation, C-F2F lecture and online recitation, and D-online lecture and online recitation [86].

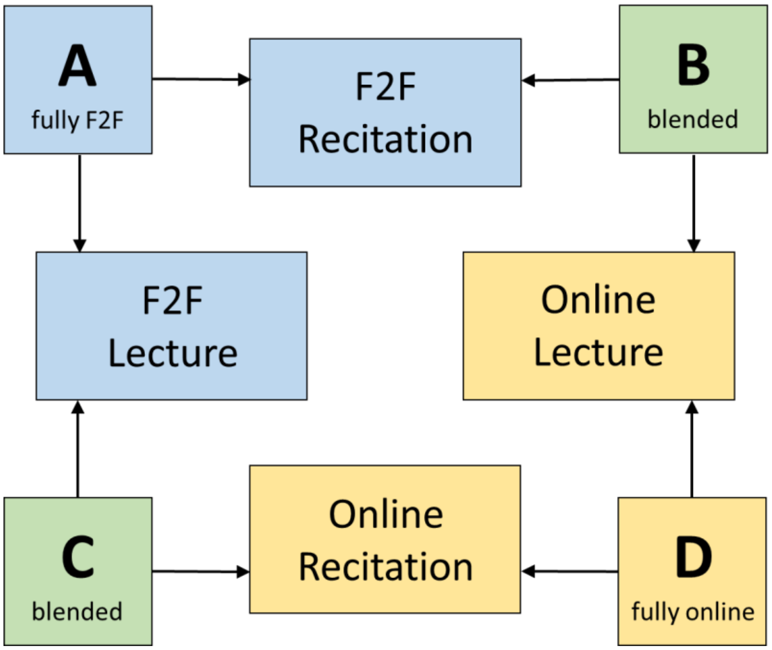


Figure 2.4. Lecture and recitation combinations available as part of CHEM 1310 redesign

2.4. DATA ANALYSIS AND RESULTS

To determine the effectiveness of the student-choice model relative to the pre-redesign semesters that were operated using a solely traditional format, statistical tests were used. While a goal of the redesign was to improve efficiency through the accommodation of more students using limited resources, it was also necessary to ensure that student performance was not detrimentally affected by maintaining or improving upon the baseline levels established during the pre-redesign semesters. A straightforward way to observe changes to student performance is the comparison of average scores for each available grade category. While these performance plots are useful in visualizing the fluctuations, it is also important to identify whether the differences in semesters and especially self-selected groups were statistically significant different from one another. Statistical significance is important for determining whether the differences observed between analyzed factors, in this study year and self-selected group, are due to random chance or actual differences. The statistical technique used here was the one-way analysis of variance (one-way ANOVA) statistical test which was performed in the MiniTab® statistical software program [76]. For an additional clarification, a post-hoc test was used to more specifically determine where significant differences existed; for this study, the Tukey post-hoc test was used [86]. As a final description of any identified changes to student performance, the size of the effect was determined.

2.4.1 Data Preparation. For the one-way ANOVA to be used, the data must satisfy the conditions of being parametric. As a first condition for utilizing the one-way ANOVA it is necessary to have a continuous dependent variable, the response variable, and an independent variable (factor) which must be at least two or more discrete categories. Responses within each of these categories should not overlap to be in more than one category [77]. As part of this study, the available data from each semester were collected and organized to create a consistent, unified database of individual grade categories. For each student grade category (clickers, homework, recitation, and exams) grades were standardized through conversion into percentage scores. Data from each year were then analyzed using Minitab® statistical software, version 17.3.1 [76].

Another requirement for performing the one-way ANOVA statistical test was the removal of outliers. The outliers were removed from the data for each semester based on two criteria. First, students having multiple incomplete grade categories were removed due to the lack of recorded grades making them statistically insignificant due to lack of participation. After the initial remover of incomplete student outliers through direct inspection, further outliers were removed if the grade was +/- 2.5 sigma or standard deviations beyond the average of the remaining student performance categories [77].

As a final consideration, when using one-way ANOVA it is important that the dataset to have a normal distribution. Based on the number of samples for each category involved in the study being well over a minimum of fifty, the responses are considered to be normally distributed based on the Central Limit Theorem [77]. The Central Limit Theorem states that that “if we draw a large enough sample from a population, then the distribution of the sample mean is approximately normal, no matter what population the sample was drawn from” [77]. From this, the dataset for each graded category (clickers, homework, recitation, exams, and overall scores) during both fall and spring semesters and within each self-selected group are considered to have a normal distribution.

2.4.2 One-Way Analysis of Variance. One-way ANOVA was used due to its ability to compare data between groups where three or more groups are present. The first independent category used for the data analyzed here encompassed nine years of study for both spring and fall semesters. The second category, which focused solely on the redesign related to the four self-selected groups of the student-choice model. For both categorical analyses, one-way ANOVA was the most appropriate method for statistical analysis.

When determining whether statistically significant differences exist, use of a one-way ANOVA determines whether a set of data supports or rejects the null hypothesis. As a determination of statistical significance, or lack thereof, the null hypothesis used in a one-way ANOVA assumes that all individual category means are equal to the grand mean of all categories. A data set found to support the null hypothesis by a p-value greater than 0.05 indicates that the given set of data appears to have no significant differences between the categories analyzed. The null hypothesis not being supported, as indicated by a p-value less than 0.05 means that significant differences exist between the means of the categories studied which cannot be attributed to random chance. In order to identify the specific instances where categories appear to be significantly different requires the use of a post-hoc test [77].

In cases where the one-way ANOVA rejects the null hypothesis indicating unequal means between categories it is necessary to identify where specific differences exist within the data set. The method used to identify where specific differences exist between analyzed categories involves the use of a post-hoc test. While there are a variety of post-hoc tests available, for the response data analyzed here the Tukey post-hoc test was used. Tukey post-hoc, also known as Tukey's HSD test, was designed for situations where each category has approximately equal sample sizes and requires that the certain statistical assumptions including normality, homogeneity, and independence are met as the data presented is in this study [77, 78].

2.4.3 Size of Effect. While the use of a one-way ANOVA and post-hoc test can indicate where significant differences exist between analyzed categories, the size of an effect must should also be included as a statistical descriptor. The size of effect is important for indicating how much statistically analyzed groups differ from one another where significant differences are shown to exist. While there are many available methods for indicating the size of an effect, based on the information studied, Eta Squared (η^2) was used. Eta Squared compares the sum of squares of an effect with the total sum of squares for the analysis; the sum of the squared deviations for all observed values [77, 79, 80]. Effect size is typically assessed based on set values for small, medium, and large effects as given in Table 2.1 [81].

Table 2.1. Effect size based on eta-squared (η^2)

Effect Size	Small	Medium	Large
η^2	0.01	0.06	0.14

2.4.4 Findings Regarding Student Lecture Preference. As stated, the Student-Choice model employed as part of the general chemistry redesign gave students four different options for participating in the course. These options as summarized in Figure 2.4, include fully F2F lecture and recitation, fully online lecture and recitation, or two hybrid options that combine the F2F and online lecture and recitation options. During pre-semester registration sessions, students enrolled in their preferred option. At the beginning of the semester all students were placed into a mandatory rotation so that they could experience all the options and make a more informed choice. Students could choose to remain with the selection they had originally made or choose a different combination of options for course participation. During the first semester of full implementation in 2011 of the Student-Choice model, the requirement was to maintain equivalent numbers of students in both online and F2F options. After 2012, the enrollment restriction had been lifted and students were fully able to avail themselves of the choices. This resulted in consistent change to initial and final student choices for their preferred lecture experience, F2F or synchronous online, which are shown in Figures 2.5 – 2.9.

From the data on student choice before and after the mandatory rotation, multiple pertinent observations can be made. After the 2012 enrollment restrictions were lifted, an immediate initial preference for the F2F lecture option over the online lecture option can be seen.

Over time, initial preference for F2F lecture option continued to reduce while initial preference for the online lecture option tended to increase. In addition to the change in initial preference, throughout the study a generally increasing number of students made the switch from the F2F lecture option to the online lecture option while the reverse trend exists for students switching from online to F2F. Starting in 2013 this pattern led to a shift towards students favoring the online lecture option over the F2F lecture option.

2.4.5 Comparing Traditional Versus Student-Choice Model. In studying the effectiveness of the Student-Choice model with regards to student outcomes, one-way ANOVA and Tukey post-hoc were conducted on student performance with regards to the following variables: clicker scores, homework scores, and final student percentage score in the course. An initial analysis was performed to determine whether any significant differences existed between all fall semesters from 2008 – 2016.

An initial one-way ANOVA comparing the pre-redesign semesters to the post-redesign semesters indicated apparent significant differences existed, with an $\eta^2 = 0.006$ A one-way ANOVA of clicker scores with fall semesters as a factor rejected the null hypothesis indicating significant differences existed between clicker scores for the years studied, $F(8, 6754) = 50.55$, $p < 0.001$, and an $\eta^2 = 0.006$ indicating that redesign had a small observed effect size on clicker performance.

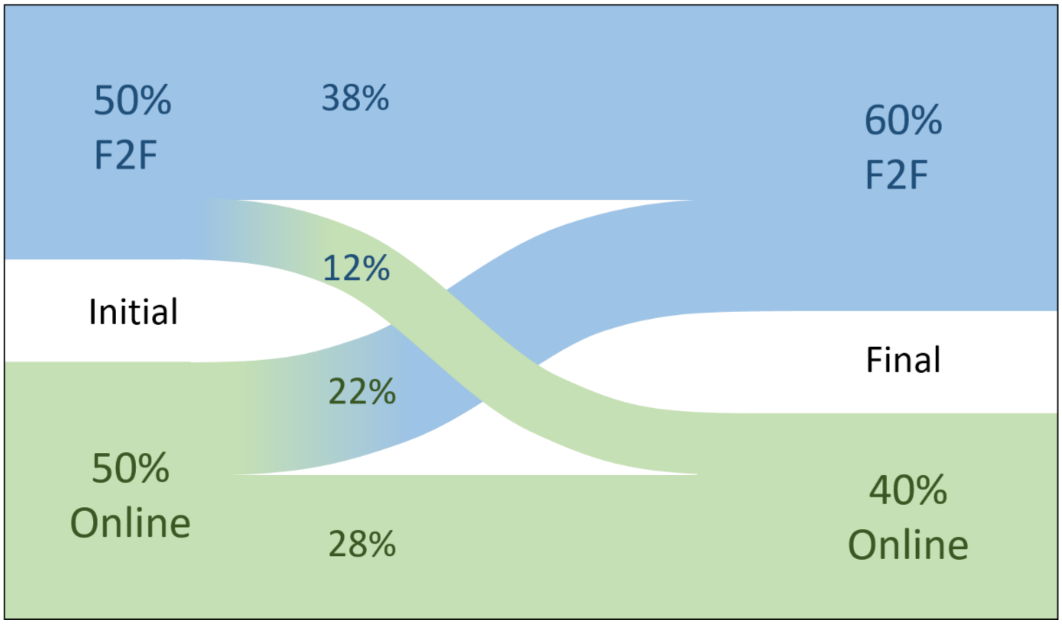


Figure 2.5. Student lecture preference, 2012

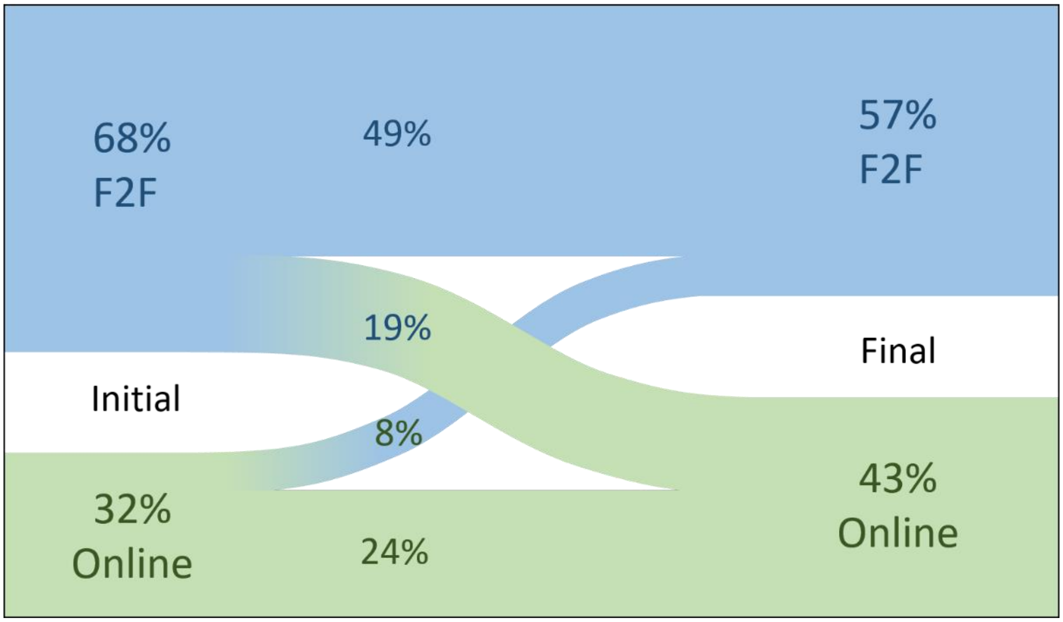


Figure 2.6. Student lecture preference, 2013

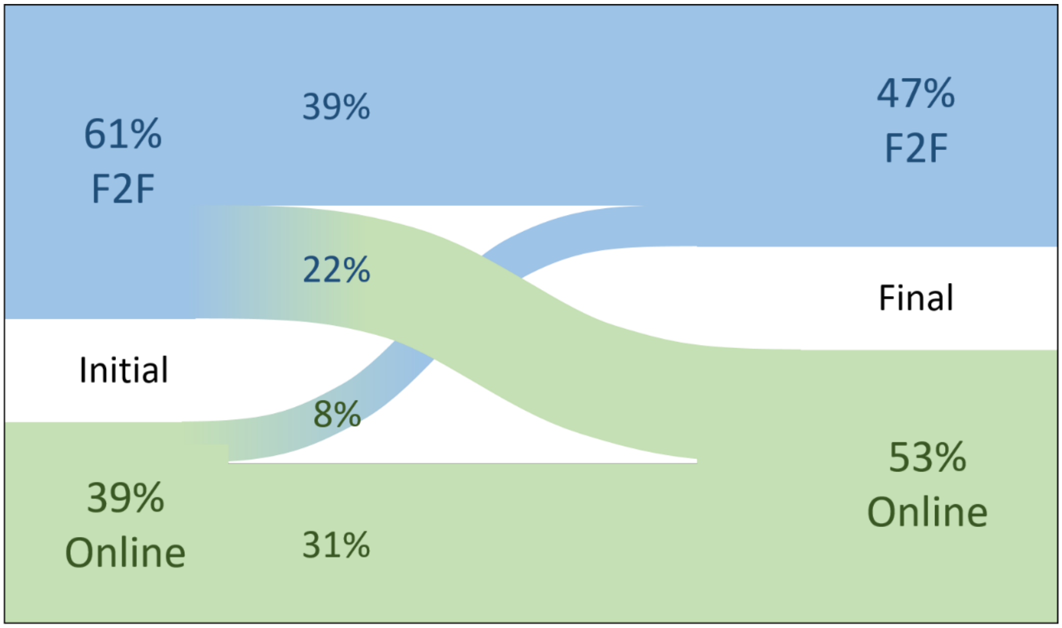


Figure 2.7. Student lecture preference, 2014

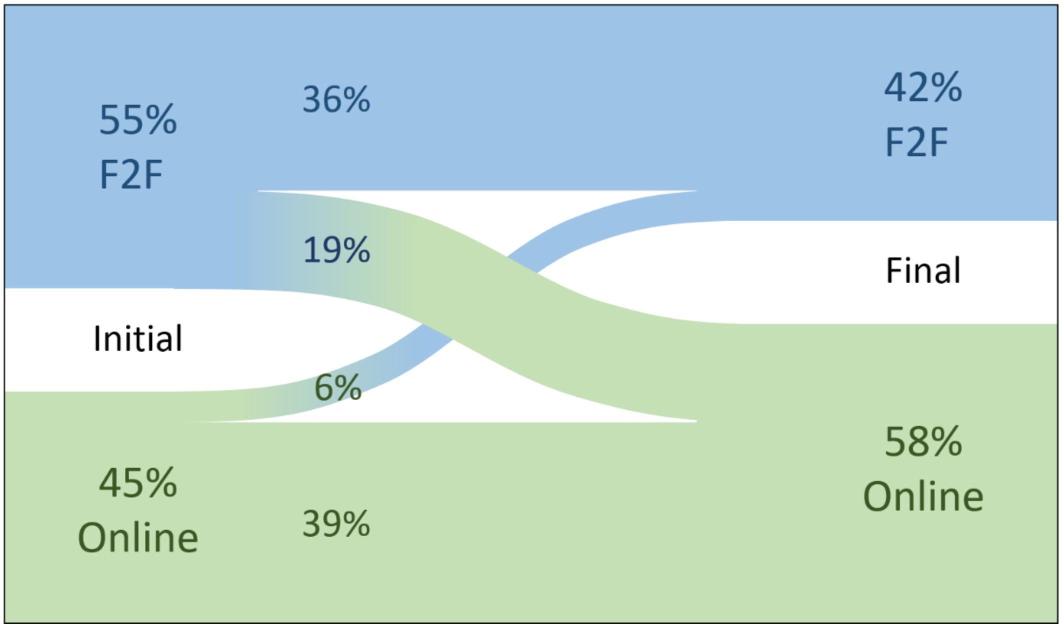


Figure 2.8. Student lecture preference, 2015

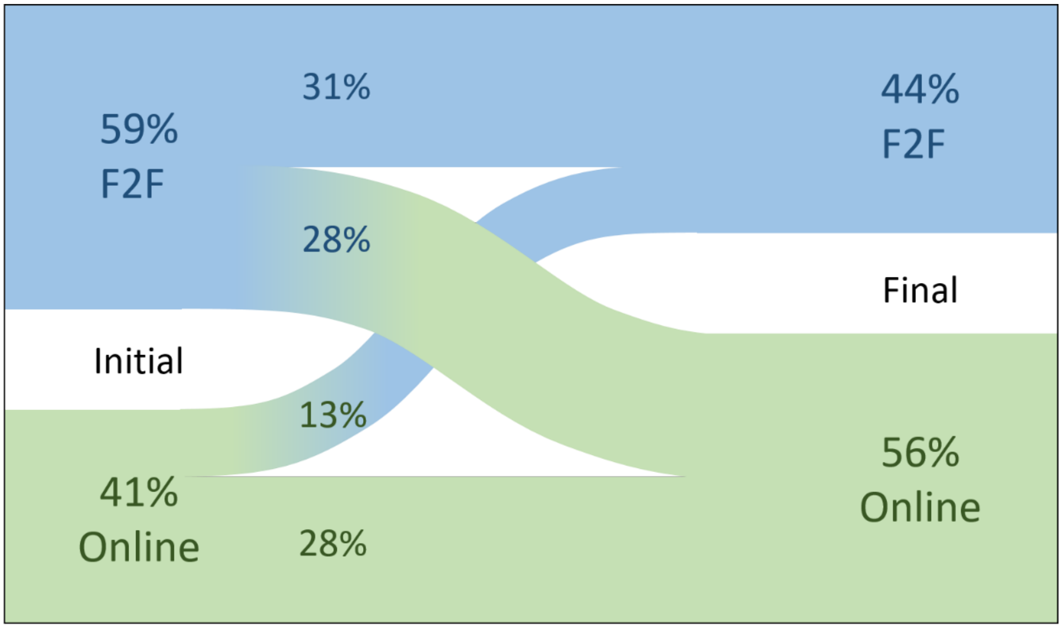


Figure 2.9. Student lecture preference, 2016

Tukey post-hoc was used to further determine which semesters were significantly different and is given in Figure 2.10.

Tukey post-hoc indicated that significant differences appeared between most semesters of the study with most semesters indicating significant differences from one another. The large number of paired (Tukey comparisons in line with each other) indicates a likelihood that clickers were neither influenced positively or negatively by the redesign. This can be further seen from a plot of mean clicker scores from 2008 – 2016 shown in Figure 2.11.

While there are noticeable drops in performance during the 2009, 2012, and 2013 fall semesters, scores tended to remain consistent with most students maintaining an average score above 90%, or an A grade, as related to clickers. It is important to note that for each means plot, the standard error was used as opposed to the standard deviation.

While the standard deviation of the grade distributions is expectedly quite large due to students receiving very different grades, the standard error of the mean is small, indicating that the mean is calculated quite accurately.

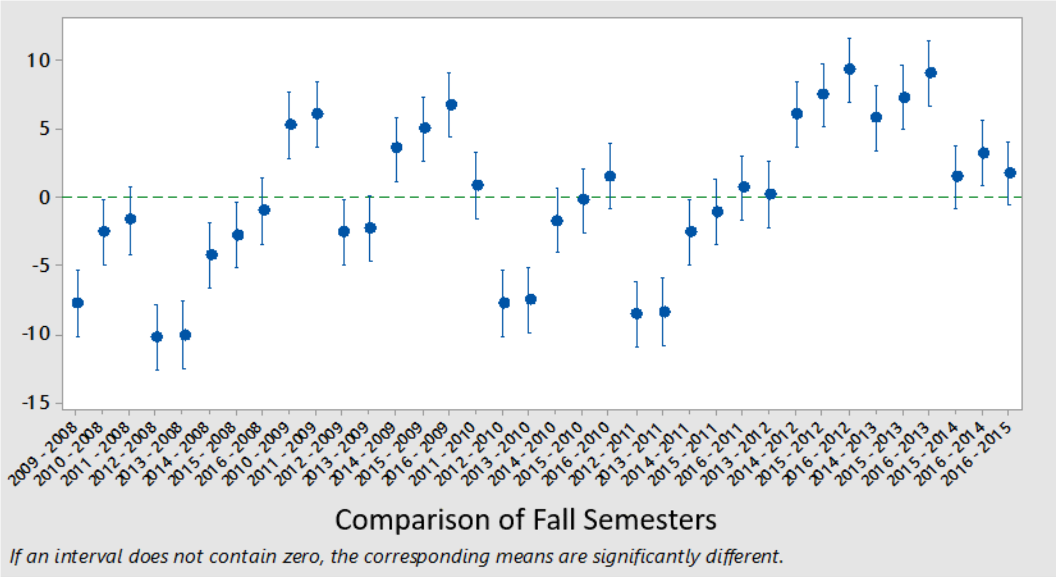


Figure 2.10. Tukey interval plot of fall semester CHEM 1310 clicker percentage scores, 2008 – 2016

Similar to clicker scores, one-way ANOVA comparing homework scores between the pre-redesign and post-redesign semesters indicated apparent significant differences existed with an $\eta^2 = 0.05$. Additionally, one-way ANOVA of the homework scores rejected the null hypothesis indicating significant differences existed within the years studied, $F(8, 6762) = 61.91$, $p < 0.001$, and that year was a factor. The value for the observed effect size comparing pre- and post-redesign years was $\eta^2 = 0.05$ indicating a small to medium effect size in favor of the redesign.

Tukey post-hoc (Figure 2.12) further indicated significant differences between the years studied. While significant differences existed, pre-redesign years did not appear to be significantly different from one another. Post-redesign years also did not appear to be significantly different from one another.

In addition to the appearance of statistical similarities observed within pre- and post-redesign years as relates to homework performance it can be seen in Figure 2.13 that homework scores were 5 – 10% higher after course redesign.

2.4.6 Analysis of Student-Choice Groups. In addition to a comparison of semesters before and after implementation of the redesign, it was also important to determine whether there was any effect on student performance based on self-selected groups. As indicated earlier, the self-selected groups consisted of: (A) F2F lecture and recitation, (B) online lecture and F2F recitation, (C) F2F lecture and online recitation, (D) online lecture and recitation.

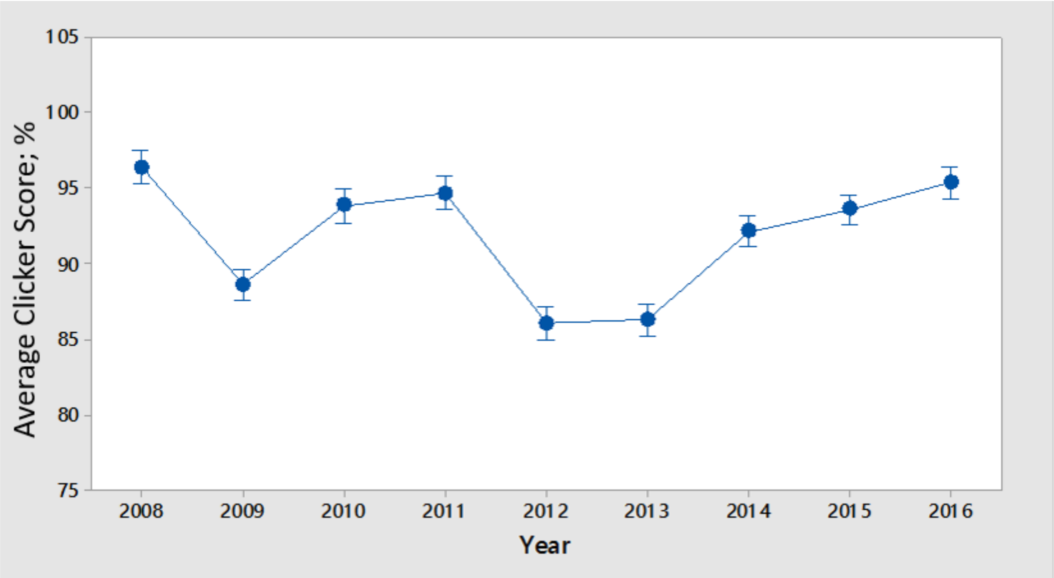


Figure 2.11. Average fall semester CHEM 1310 clicker percentage scores, 2008 – 2016

One-way ANOVA of clicker scores for students with the given self-selected groups during post-redesign years, 2012 – 2016, as a factor indicate that significant differences were present [F(3, 3897) = 11.87, $p < 0.001$] though the size of the observed effect size was small with a value of $\eta^2 = 0.009$.

Tukey post-hoc of clicker performance, represented in Figure 2.14, clarified that while the fully F2F group was signifcantly different than all other self-selected groups, all other groups did not appear to be significantly different.

Further analysis of average clicker scores indicates that those students choosing the fully F2F course option achieved a higher performance than those represented in the other self-selected groups (Figure 2.15).

A one-way ANOVA of homework scores indicated no significant differences between any of the self-selected groups, [F(3, 3897) = 0.63, $p < 0.594$]. While Tukey post-hoc and η^2 were unnecessary based on the results of the one-way ANOVA, a means plot shown in Figure 2.16 for the self-selected groups indicated that the highest grade variance was within group C (F2F lecture and online recitation).

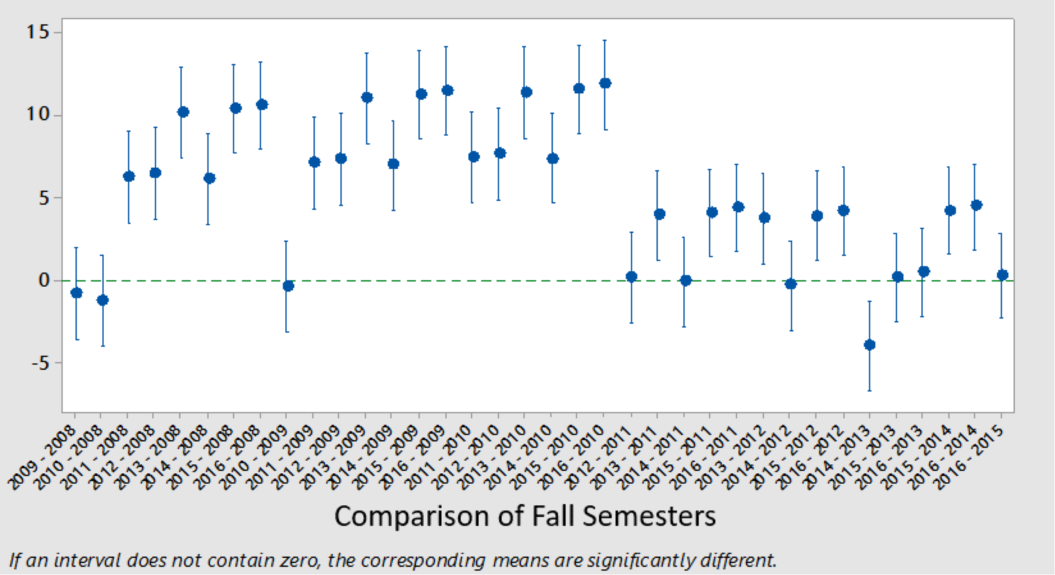


Figure 2.12. Tukey interval plot of fall semester CHEM 1310 homework percentage scores, 2008 – 2016

2.5. SUMMARY

Lecture redesign accomplished multiple goals specified as necessary for implementation of a successful redesign. Offering F2F and online synchronous sections allowed for the accommodation of more students using a reduced pool of resources including physical space and personnel. Additionally, by offering students an opportunity to try both options as part of this student-choice model, the online lecture option became increasingly popular. The consistently higher student preference for the online lecture compared to the F2F option indicates continued viability of this option for handling increased enrollment without a need to add lecture sections.

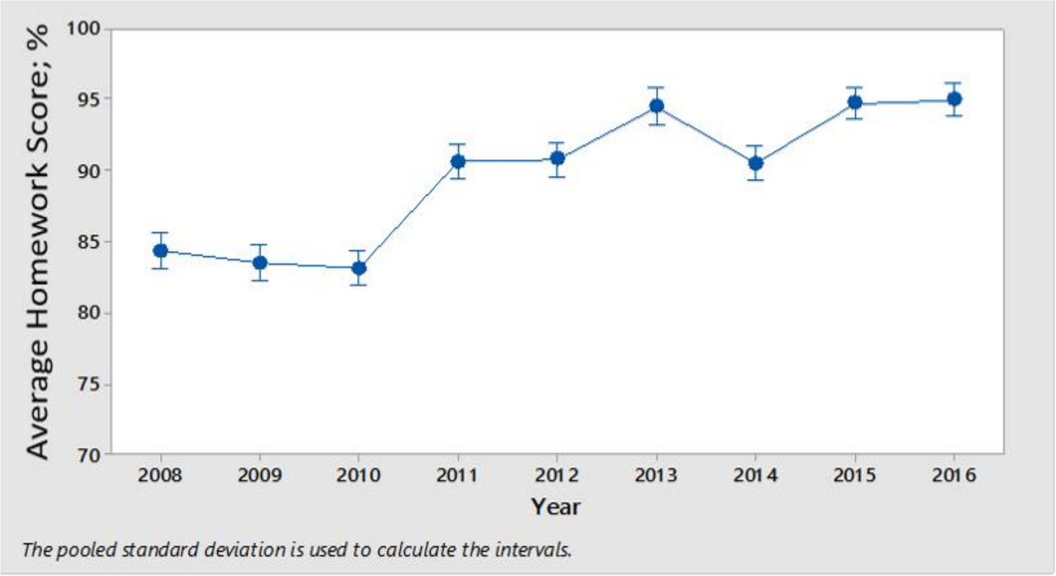


Figure 2.13. Average fall semester CHEM 1310 homework percentage scores, 2008 – 2016

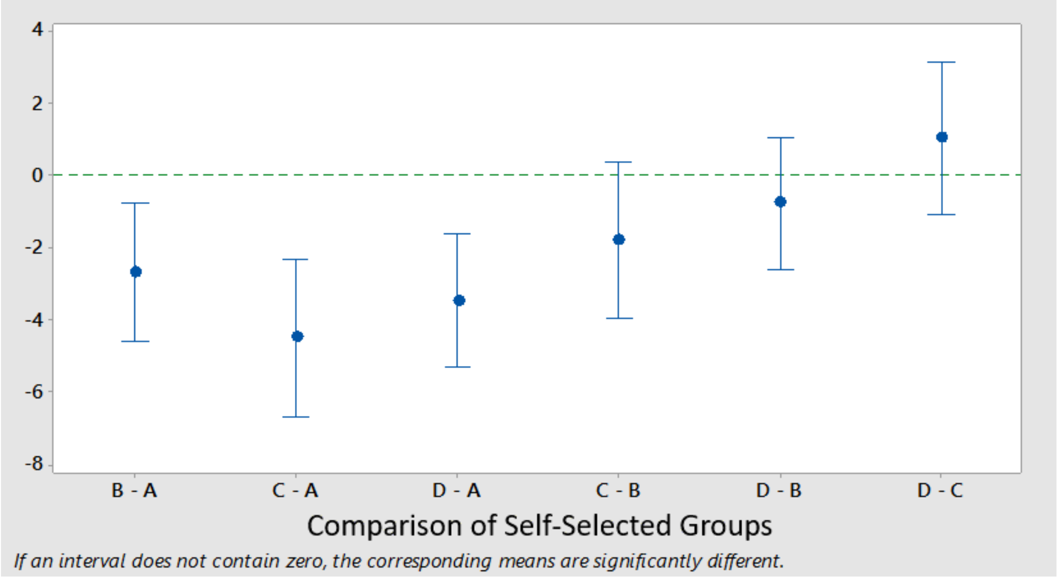


Figure 2.14. Tukey interval plot of fall semester CHEM 1310 clicker scores between self-selected groups, 2012 – 2016

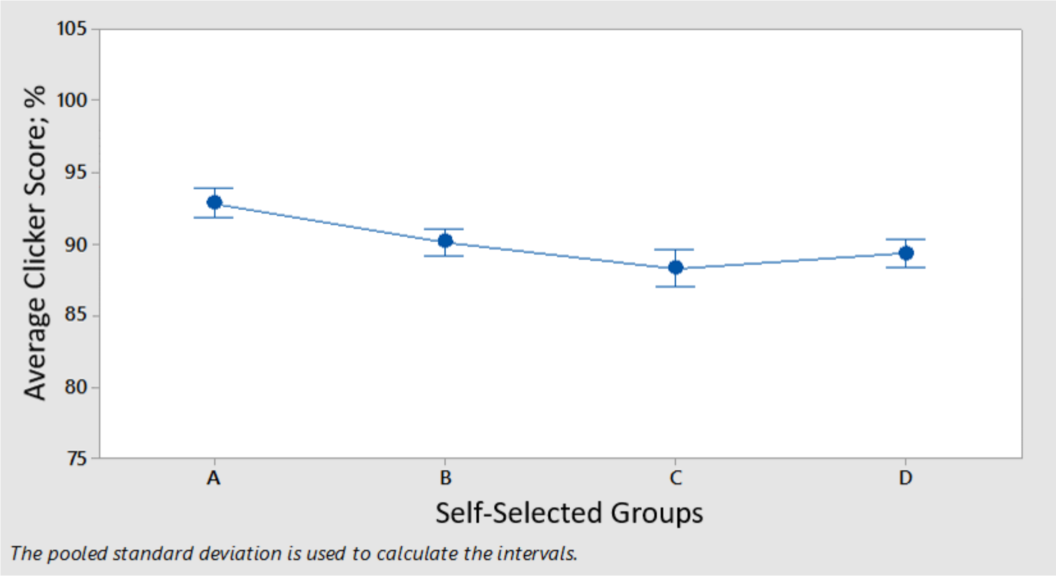


Figure 2.15. Average fall semester CHEM 1310 clicker scores of self-selected groups, 2012 – 2016

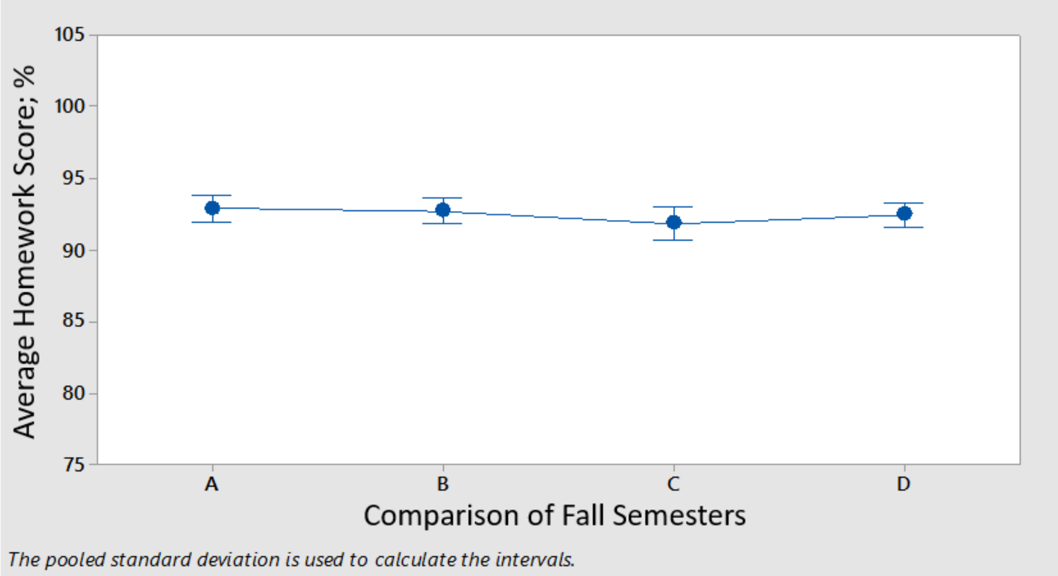


Figure 2.16. Average fall semester CHEM 1310 homework scores of self-selected groups, 2012 – 2016

As relates to student performance, it was clear that there was no general relationship or change in student clicker scores between the pre- and post-redesign semesters. Within post-redesign semesters, data indicated that those students enrolled in the fully F2F section, group A, had significantly higher clicker scores than those students in the other self-selected groups. While this could be attributed to students having a higher focus on the lecture when present in the physical lecture space, this becomes less impactful based on the lower observed performance of students in group C who also participated via F2F lecture.

Where the redesign showed positive results related to performance data is the homework performance. Statistically, students in the redesign semesters had higher homework scores on average than those in the pre-redesign semesters. Additionally, implementation of student-choice for lecture appeared to have had no statistically significant impact on student performance as students in all self-selected groups appeared to have statistically equivalent scores.

While the look at lecture redesign is important, it was only one aspect of the redesign. By analyzing the changes to lecture and its seeming effect on student performance, only a portion of the effectiveness of the student-choice model as implemented can be seen. To see the full scope of this redesign it is necessary to determine any effect that can be seen due to the changes to the traditionally used recitations in general chemistry.

3. RECITATION REDESIGN DURING THE FALL SEMESTERS

3.1. THE ROLE OF RECITATIONS

An important part of many gatekeeper courses is the use of recitations as a supplemental course component. In a typical recitation, students in the course, are split into smaller cohorts in order to decrease the student-instructor ratio. The smaller number of students in the recitation is intended to offer a more comfortable opportunity to engage in discussion of topics presented during prior lecture sessions. The larger lecture setting often found in gatekeeper courses can discourage discussion either by students who are uncomfortable in such a large group of peers, or by the need of the instructor to move on to maintain the schedule of topics. By using recitations, student queries have an opportunity to be addressed and more fully discussed [22, 44, 86].

As a course tool, recitations have maintained a high level of popularity and usage within many gatekeeper courses, particularly those in lower level science, technology, engineering, and math (STEM) courses. This popularity can be attributed to the needs represented in STEM gatekeeper courses to accommodate the large variety of student majors who may need more assistance in a field unrelated to their chosen major. Further, for students new to the university environment, recitation can be an opportunity to acclimate them to good habits for success in a course using a course setting with which they are more familiar [22, 44, 86].

3.2. RECITATION AT MISSOURI S&T

At Missouri S&T, recitations have remained a constant fixture for all students taking the general chemistry gatekeeper course. Traditionally, each general chemistry lecture section was supplemented by eight recitation sections led by an assigned GTA. This resulted in 32 separate recitation sections each fall semester and 8 during each spring semester. Recitations were scheduled as 50 minute sessions with the final 15 – 20 minutes of each session dedicated to completion of a quiz encompassing topics covered during the previous week’s lecture. In order to accommodate the large number of sections needed, recitations were scheduled only on non-lecture days of the week, with recitations for different lecture sections operating concurrently. In the fall semesters prior to the major course redesign, it was common for four separate recitation sections to run simultaneously during a given hour each morning [86].

Prior to the redesign, changes were made to improve the functionality and subsequent value of general chemistry recitations. In order to give students more time for discussion and practice, recitation quizzes were moved to a special open session later during the recitation day. By doing this, GTAs could spend more time assisting students with discussion of course topics and use of examples during scheduled recitations. In addition to having quizzes during a later moderated session, quizzes were also converted to an online format utilizing the online homework system already in use for multiple years. An advantage of online quizzes was in their self-graded nature. Previously, each GTA graded quizzes only for their assigned recitation sections which had the potential of generating grade inconsistency between different recitation sections. The self-graded aspect of the online recitation quizzes reduced the grading burden significantly for GTAs allowing them more opportunities for assisting students. Another effect of having asynchronous quizzes was in giving students a chance to self-practice and better familiarize themselves with the material prior to taking the quiz. This was not possible in the previous arrangement [86].

General chemistry recitations were considered positive for their role as an opportunity to increase available discussion and practice though other issues still persisted. Increased enrollment had already required the opening of an additional lecture section during the spring semester, supplemented by an additional 8 recitation sections. Despite this change, enrollment would continue to increase, which would create a need for more resources in the form of space and personnel. Increased need for space was a constant issue with many appropriate classrooms being unavailable in the spring semester. If the space issue could be solved there was still the issue of personnel who were generally occupied in spring semesters with other teaching responsibilities [86].

Along with issues related to personnel the other issue was maintaining the quality of the recitation sessions as a tool for general chemistry instruction. While the purpose of recitation was to promote discussion through examples and practice problems, no two recitations were operated in the same fashion. Each GTA had a free hand to run their individual recitation sections in the way that suited them. To this end, many recitations became additional lecture sessions with minimal opportunities for discussion [86].

3.3. REDESIGN OF TRADITIONAL FACE-TO-FACE RECITATION

As part of the general chemistry course redesign, recitations were restructured by changing the format to be more inducing of student discussion. Prior recitations, which often served as instructor-centered lecture-styled discussion sessions, were converted into active and collaborative problem-solving centers. Students in recitation were divided into random groups of 2-3 students who would receive a packet of questions ranging from lower-level single-topic questions to higher-level questions requiring the combination of lower-level ideas. Student groups would each work standing at a board (marker or chalk) and collaboratively discuss and solve problems with a GTA support as needed. To assess gains in content knowledge from the collaborative session, at the end of the collaborative recitations students took a paper quiz related to material practiced in recitation. Student quizzes were individual rather than group assignments to encourage each student’s full participation in their own skill development and not become overly reliant on the skills of their assigned partners.

In order to successfully implement the more active, collaborative recitation sessions other aspects of the course required adjustments. In order to have longer recitation session, the lecture was reduced by one hour per week, time that was used to increase recitation to a two-hour weekly session. It was also necessary to make changes to the role of GTAs during recitation. Prior to redesign, GTAs conducted lectures in a style of their choice. In their new role, they were trained to serve as moderators. Instead of leading the discussion in a one-way manner, GTAs acted as monitors of progress and were encouraged to only offer students assistance as needed, following a guided inquiry style similar to those utilized in POGIL and PLTL strategies. GTAs would no longer be passive lecturers but act as facilitators for discussion, which, when coupled with a guided inquiry approach, made recitations more student-centered. In addition to GTA support, ULAs were assigned to each recitation. ULAs for the course were chosen based on previous course success and strong communication skills. As part of their training, ULAs were given opportunities each week to re-familiarize themselves with the topics discussed through meeting with the instructor or GTAs. ULAs primary focus was assisting students with problem solving and acting as learning guides. The use of ULAs also allowed for multiple groups to be assisted simultaneously when necessary.

Alongside changes to the face-to-face (F2F) recitation, an online recitation option was developed and implemented as part of the redesign initiative by the Governor of Missouri in collaboration with Missouri's 13 public four-year institutions of higher education and in partnership with the National Center for Academic Transformation (NCAT). The goal in developing an online recitation option was, as for the online lecture option, to more efficiently utilize available resources to improve student outcomes in the face of increasing enrollment. When developing an online option for lecture it was important to maintain an experiential parity for students between the online and F2F options, in the development of an online recitations it was considered more important to give students an experience that offered similar opportunity for growth and development as in the F2F option. However, while the redesigned F2F recitation offered active, collaborative practice with GTA and ULA support, the online recitation required students to be more self-reliant and developed more self-initiative.

Similar to F2F recitations, students enrolled in the online recitation option were assigned practice problems of increasing difficulty. Lower-level practice problems would involve basic skills with higher-level problems incorporating syntheses of those developed lower-level skills. As with the F2F option, students in the online option had 30 minutes to complete a timed quiz of equivalent difficulty to the F2F quiz. However, students in the online option were given three days to work on the assigned practice and complete the quiz, as opposed to the two hours of guided practice and a quiz in the F2F option. Students participating in the online option were encouraged to utilize, as needed, available resources such as office hours, tutoring, course discussion board, or general chemistry LEAD sessions.

Similar to the online lecture option, students indicated initial discomfort with the idea of enrolling in the online recitation option. During the mandatory sampling period, students not only experienced the online lecture option, but were also were given the opportunity to experience the online recitation option before making a final decision on the combination of options that best suited their preferred learning needs (see Figure 2.4).

3.4. DATA ANALYSIS AND RESULTS

Data collected was analyzed using statistical methods presented in section 2. One-way ANOVA with Tukey post-hoc of average recitation scores for pre- and post-redesign semesters was used to identify general effectiveness of the redesign method vs traditional instructional methods. Further, one-way ANOVA and Tukey post-hoc were used to determine whether significant statistical differences between self-selected redesign groups, A, B, C, and D existed. Additional one-way ANOVA and Tukey post-hoc analyses comparing average exam performance in pre- and post-redesign groups as well as between self-selected groups in the redesign years were completed to determine efficacy of the Student-Choice model implemented.

3.4.1 Student Preference. Along with their chosen lecture option, students enrolled in one of the two recitation options available prior to start of the semester shown in Figure 2.4. During the first three weeks of the semester, students were placed into a mandatory sampling period to make a choice in their preferred participation option based on actual experience with the available options. In the same manner that the 2012 lecture was initially restricted to a set enrollment for each option, recitation was likewise restricted until after the 2012 fall semester. All semesters post 2012 allowed for more flexibility in how many students could enroll in a given option, F2F or online. The change in student preference from the 2012 fall semester to the most recent 2016 fall semester are shown in Figures 3.1 – 3.5.

Student preference changes with regards to online options were not isolated only to the lecture. As discussed in section 2, changes were also visible relating to the favorability of the available online option over the F2F options. Due to the nature of the student-choice model used, it is important to note the general changes to student preferences with regards to the four course participation options available, as given in Figure 2.4. The overall combined preference of students regarding the four self-selected groups are summarized in Table 3.1.

In order to better visualize the changes to student preference with regards to the four course participation options a summary of the change was plotted in Figure 3.6. This summary combines the two blended options (B and C) and plots them along with the option A, fully F2F, and option D, fully online.

Figure 3.6 acts as a further indication that while students still utilize F2F options, there is an increasing preference of students to utilize some online component as part of their educational experience.

3.4.2 Traditional Versus Student-Choice Model. One-way ANOVA with student recitation quiz percentage scores as a response was performed using MiniTab (version 17.3.1) with fall semesters as the factor. This was done in order to determine whether there were any significant differences between student performance in all years pre- and post-redesign.

An initial one-way ANOVA comparison of recitation scores pre- and post-redesign indicated significant differences existed. A further one-way ANOVA comparing all years indicated a rejection of the null hypothesis meaning that there appeared to be significant differences related to student performance based on the years studied F(8, 6762) = 98.03, p < 0.001.

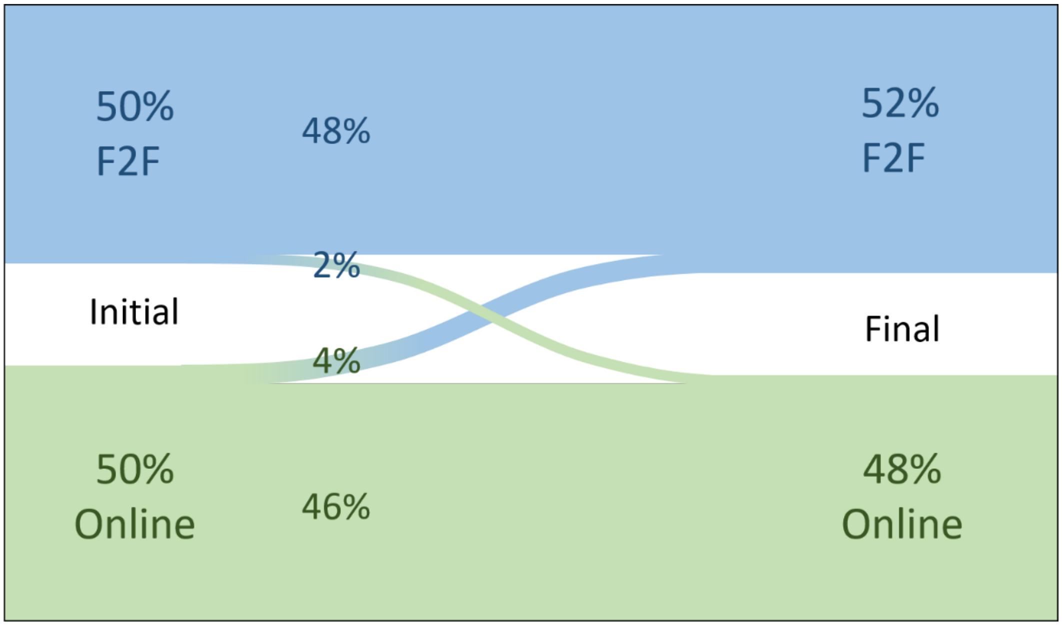


Figure 3.1. Student recitation preference, 2012

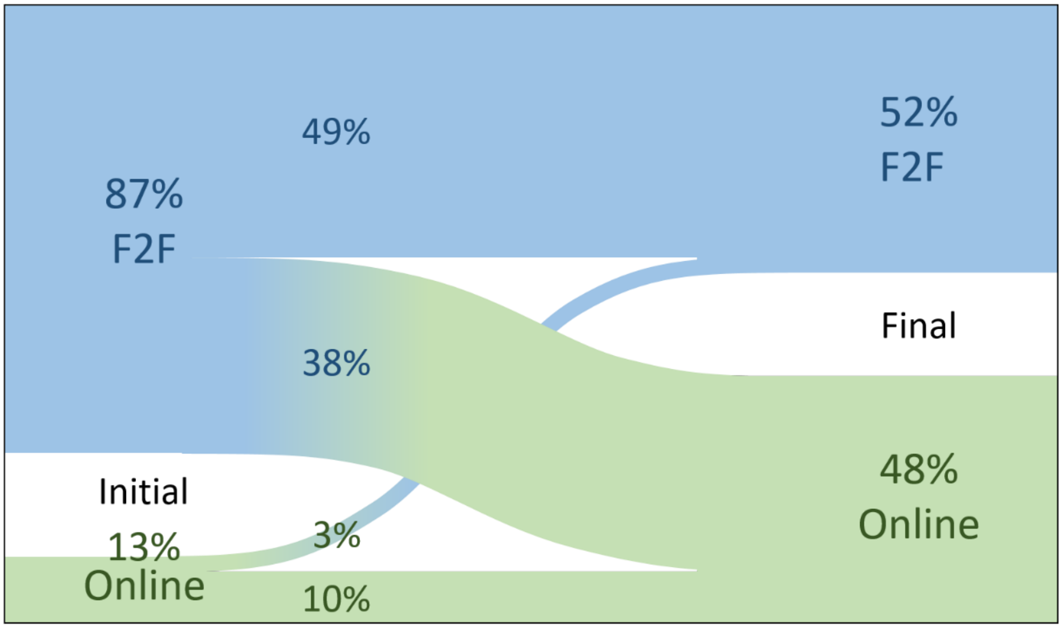


Figure 3.2. Student recitation preference, 2013

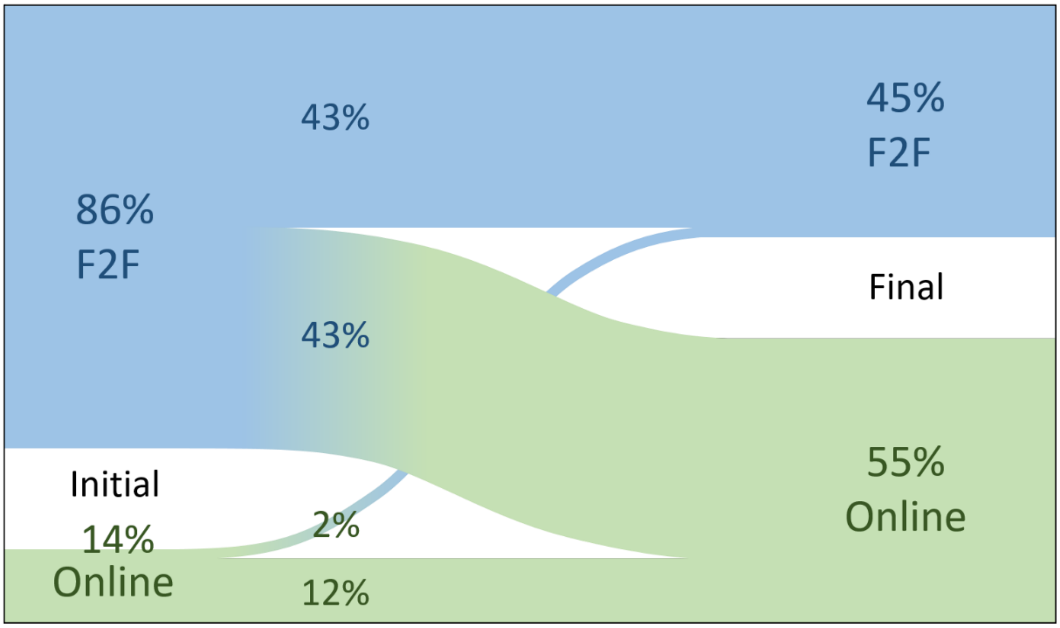


Figure 3.3. Student recitation preference, 2014

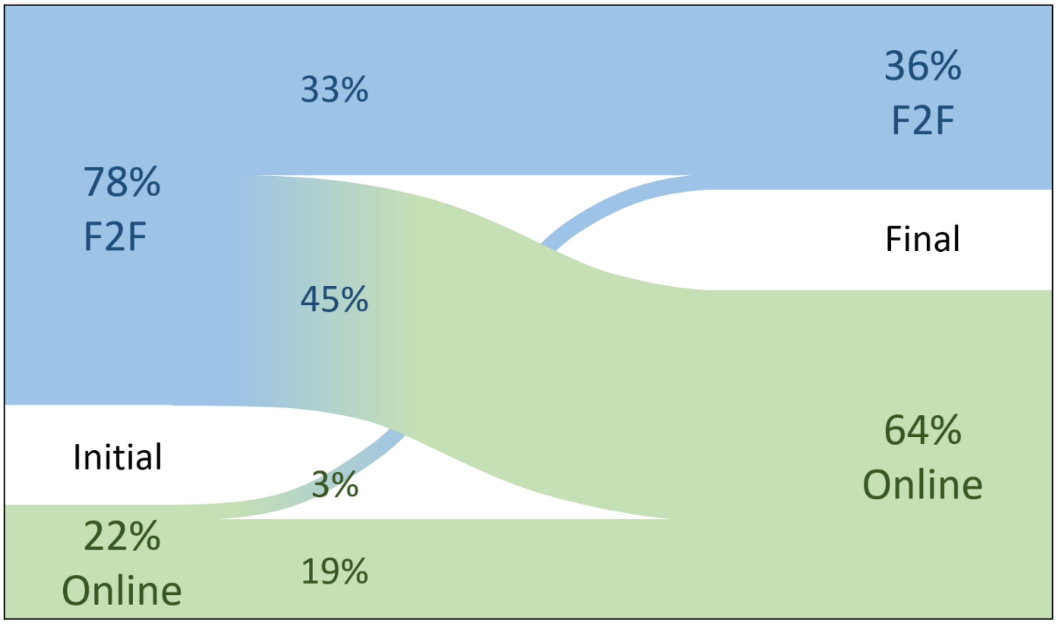


Figure 3.4. Student recitation preference, 2015

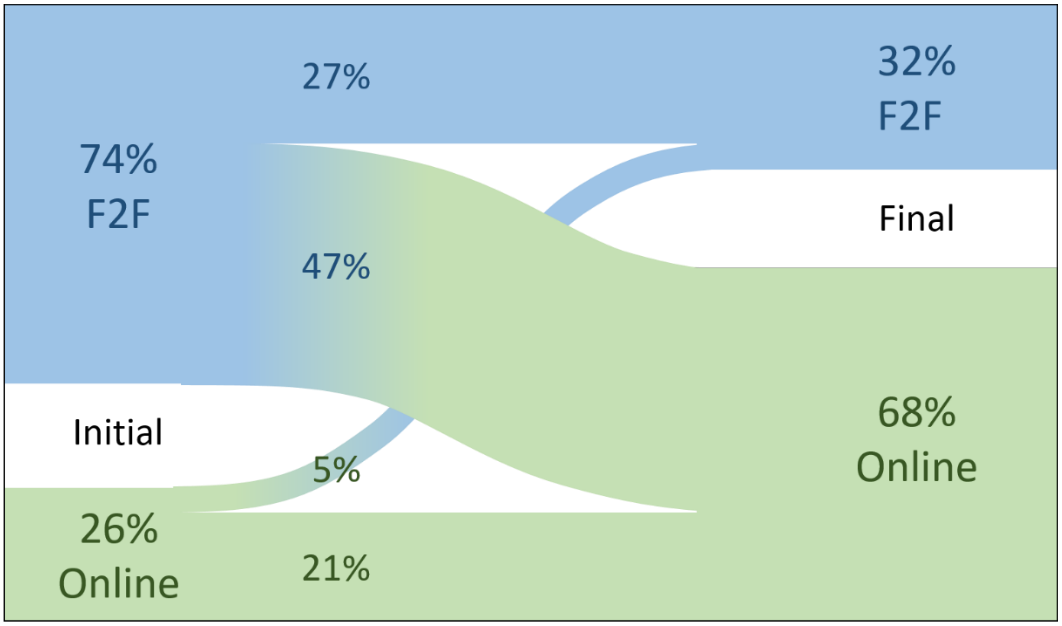


Figure 3.5. Student recitation preference, 2016

The observed effect size of the redesign was found to be small with a value of $\eta^2 = 0.005$. Tukey post-hoc was used to identify the specific instances where means significantly differed from the grand mean or where significant differences existed. (Figure 3.7).

Table 3.1. Final student preference of fall semester Student-Choice model participation options

Fall Semester	Self-Selected Groups			
(Enrolled Students)	% A	% B	% C	% D
FS 2012 (N = 751)	38.6	23.0	9.9	28.5
FS 2013 (N = 746)	32.8	24.3	19.0	23.9
FS 2014 (N = 803)	25.9	20.5	19.2	34.4
FS 2015 (N = 889)	19.6	22.8	20.0	37.6
FS 2016 (N = 842)	17.1	27.2	14.7	41.0

Similar to the analysis of clicker performance in section 2, Tukey post-hoc analysis of recitation quiz scores indicated that pre-redesign semesters were significantly different from one another and most redesign years. Tukey post-hoc also indicated that of the redesign years most appeared to not reject the null hypothesis and did not appear to have significant differences, excepting 2013 which did appear to be significantly higher. A means plot of fall semester recitation scores (Figure 3.8) indicates the changing dynamic of recitation performance pre- and post-redesign. The means plot of student recitation performance indicates a decline in performance of approximately 10% during pre-redesign years. Post-redesign years showed more consistent recitation scores excepting an observed higher performance in 2013.

It was also necessary to further focus on the redesign years and determine if any differences in student performance could be observed between self-selected groups within the Student-Choice model.

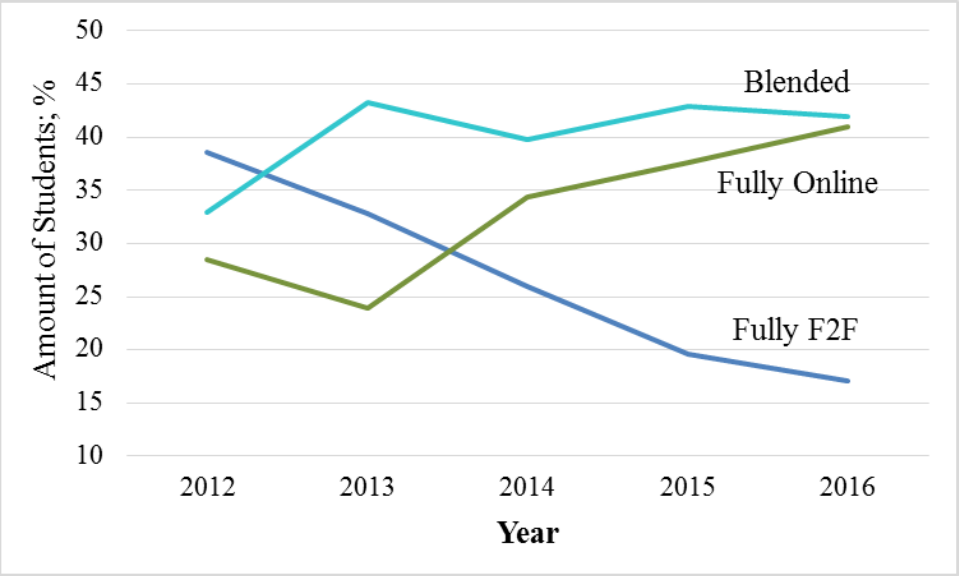


Figure 3.6. Change in student preference of Student-Choice model options, 2012 - 2016

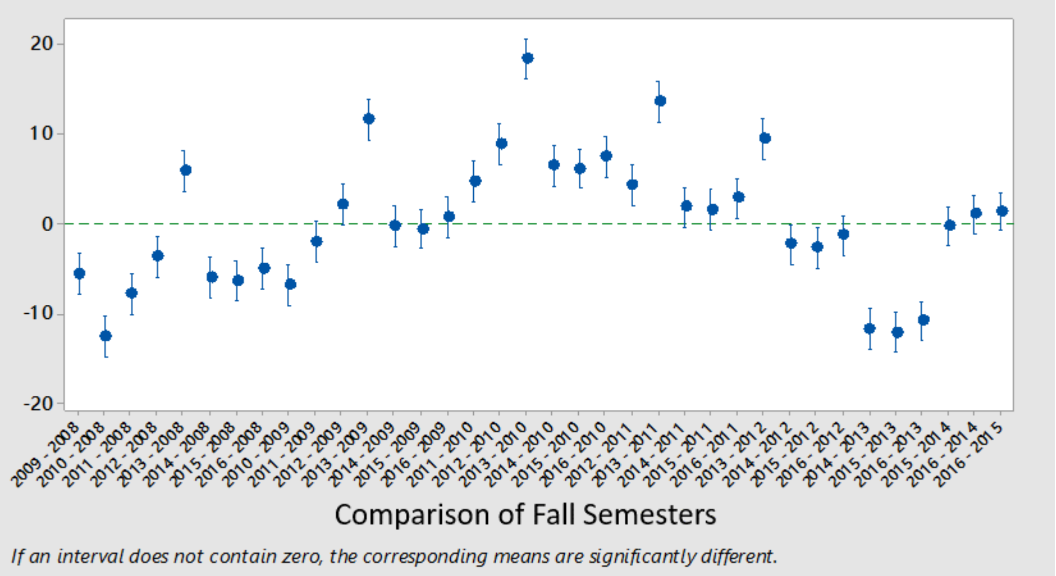


Figure 3.7. Tukey interval plot of fall semester CHEM 1310 recitation scores, 2012 – 2016

Initially, one-way ANOVA with Tukey post-hoc was performed using recitation performance as a response and self-selected groups of the Student-Choice model (Figure 2.4) as a factor. One-way ANOVA indicated a rejection of the null hypothesis [F (3, 3897) = 3.93, $p < 0.01$] meaning that there were significant differences in student performance between self-selected groups.

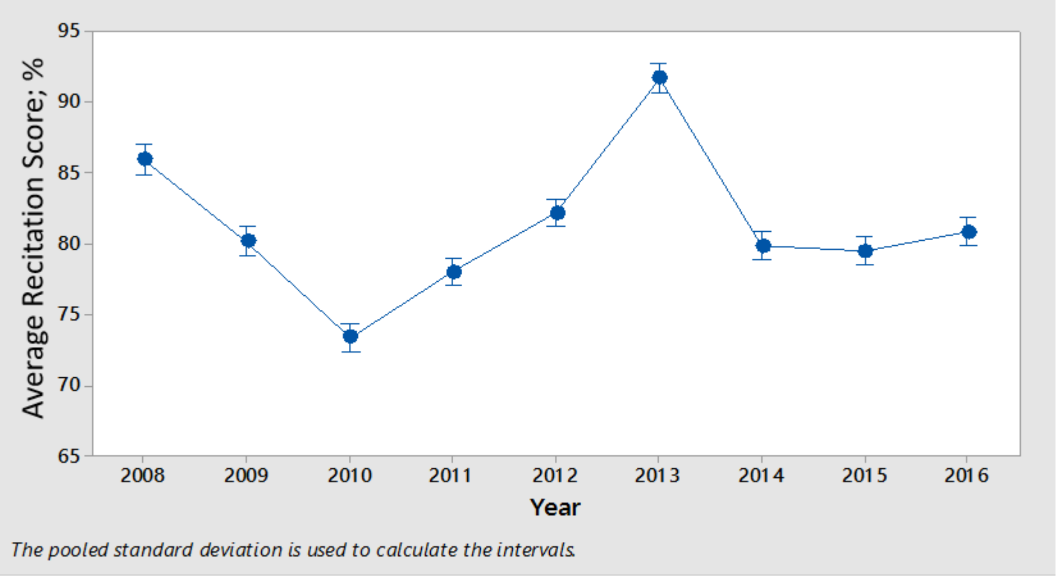


Figure 3.8. Average fall semester CHEM 1310 recitation scores, 2008 – 2016

Though significant differences existed, the observed effect size was small with a value of $\eta^2 = 0.003$. Specific instances where the null hypothesis assuming equal means had failed were identified using Tukey post-hoc (Figure 3.9). Additionally, a means plot of student performance for each of the self-selected groups for all redesign years was generated (Figure 3.10) to further observe the impact of student choice on course performance.

As a final check on the efficacy of the Student-Choice model a one-way ANOVA with Tukey post-hoc was performed to analyze if significant differences existed based on average exam scores. Results of the one-way ANOVA using average exam scores as a response and fall semesters as a factor indicate significant differences existed between the studied years [F(8, 6784) = 42.71, $p < 0.001$] with an $\eta^2 = 0.017$.

Tukey post-hoc, shown in Figure 3.11, indicated few similarities between the semesters studied. Additionally, changes to student exam performance throughout the years studied is shown in Figure 3.12.

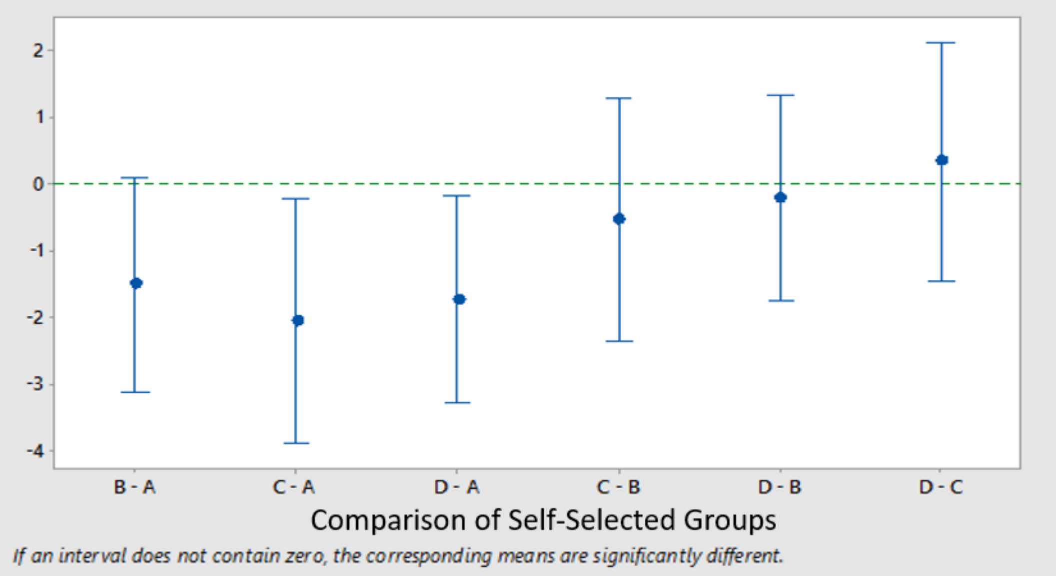
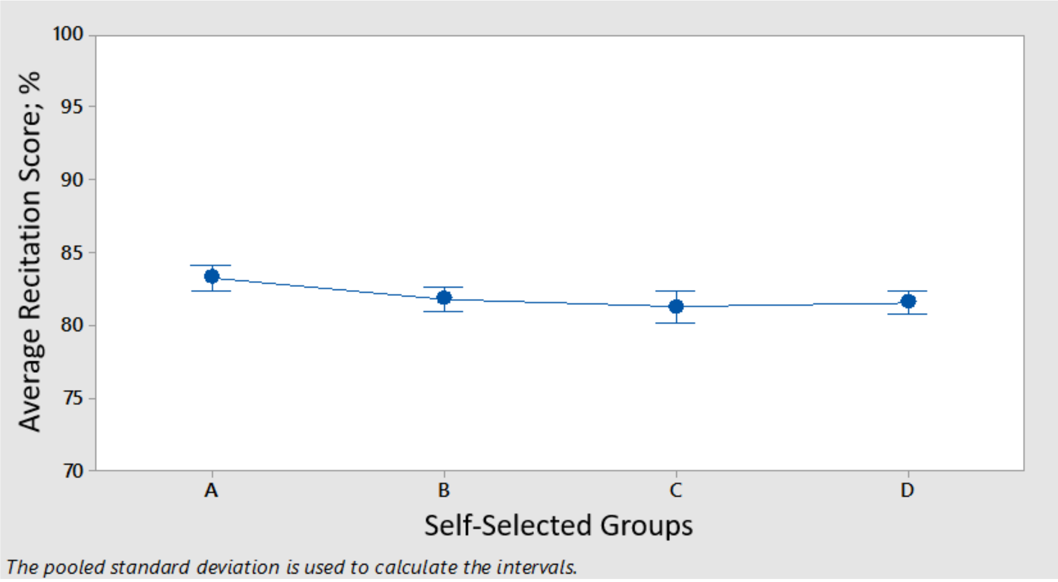


Figure 3.9. Tukey interval plot of fall semester CHEM 1310 recitation scores between self-selected groups, 2012 – 2016

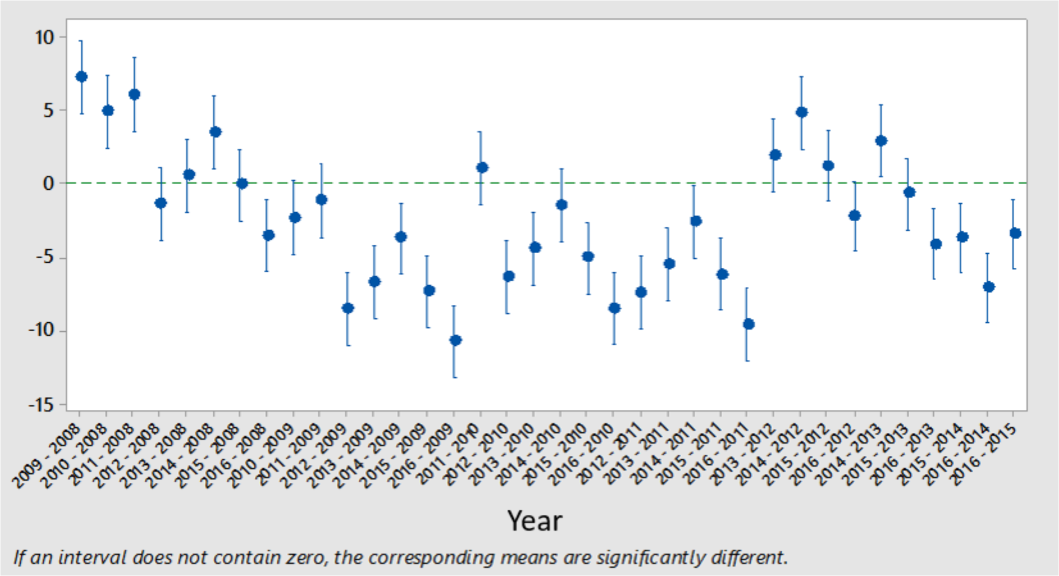
One-way ANOVA and Tukey post-hoc were performed using exam performance as a response and self-selected groups of the Student-Choice model as a factor. The one-way ANOVA indicated that there were significant differences between the self-selected groups [$F(3, 3894) = 9.47$, $p < 0.001$] with Tukey post-hoc, shown in Figure 3.13, indicating which groups were significantly different from one another. For this analysis $\eta^2 = 0.007$ indicating a small observed effect size. Average exam performance for each self-selected group is shown in Figure 3.14.

One-way ANOVA and Tukey post-hoc were performed using exam performance as a response and self-selected groups of the Student-Choice model as a factor.



The pooled standard deviation is used to calculate the intervals.

Figure 3.10 Average fall semester CHEM 1310 recitation scores of self-selected groups, 2012 - 2016



If an interval does not contain zero, the corresponding means are significantly different.

Figure 3.11. Tukey post-hoc analysis of average exam performance between years 2008 – 2016

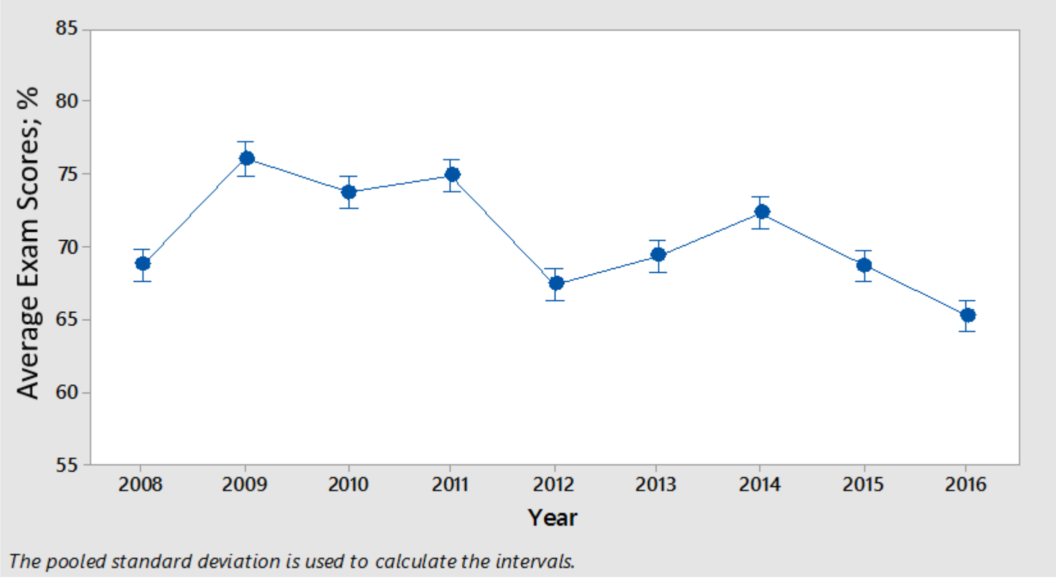


Figure 3.12. Average fall semester CHEM 1310 average exam scores, 2012 - 2016

One-way ANOVA indicated that there were significant differences between the self-selected groups [F(3, 3894) = 9.47, $p < 0.001$] with Tukey post-hoc, shown in Figure 3.13, indicating which groups were significantly different from one another. For this analysis $\eta^2 = 0.007$ indicating a small size of effect. Average exam performance for each self-selected group is shown in Figure 3.14.

Further information relating data for the fall semesters of the redesign are included as appendices. Data includes one-way ANOVA outputs along with Tukey post-hoc plots, and mean plots for overall course scores for all fall semesters. Additional appendices include statistical analysis of discussed grade categories (clicker, homework, recitation, exam, and overall course scores) for each individual year of the redesign with self-selected groups as the factor.

3.5. SUMMARY

Redesigning recitation along with the lecture was a necessary and important step in committing to a successful course redesign as directed by the Governor’s initiative. Through redesign, the F2F recitation changed from a passive, lecture-style session to an active and collaborative problem-solving opportunity for participating students. Based on the findings from the recitation quiz scores given in section 3.2.4, the addition of an online recitation section gave students an opportunity to make the choice that better suited their learning needs, without sacrificing the general educational experience when

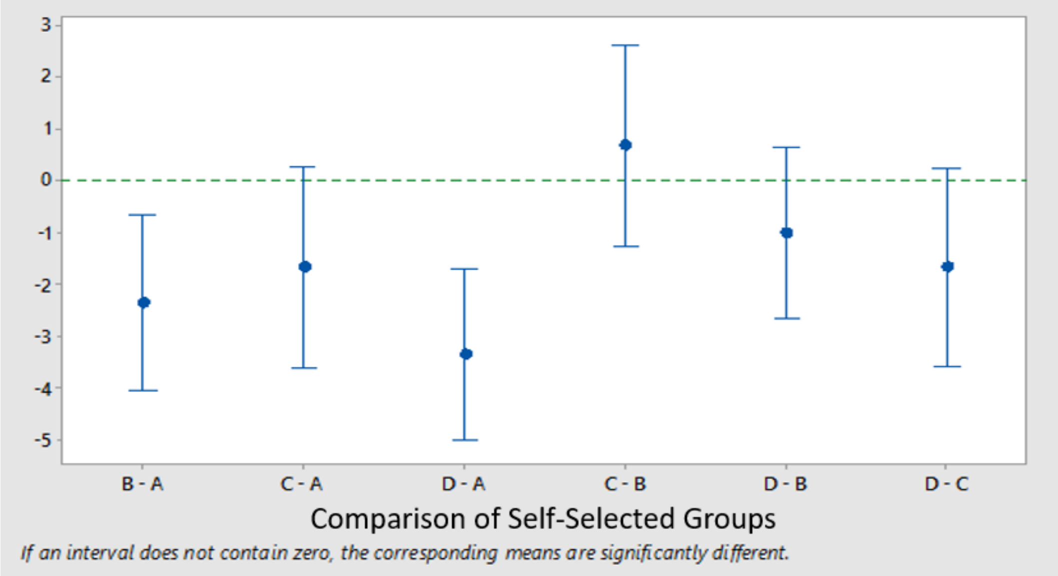


Figure 3.13 Tukey interval plot of fall semester CHEM 1310 average exam scores between self-selected groups, 2012 – 2016

compared to the previously passive traditional recitation sessions used. While both recitation options had the same goals, they offered differing approaches.

F2F sessions offered an assisted experience focusing on active and collaborative learning experiences. The online recitation option allowed students more flexibility in their schedule but required independence and development of strong self-management skills in order to improve their proficiency within the course.

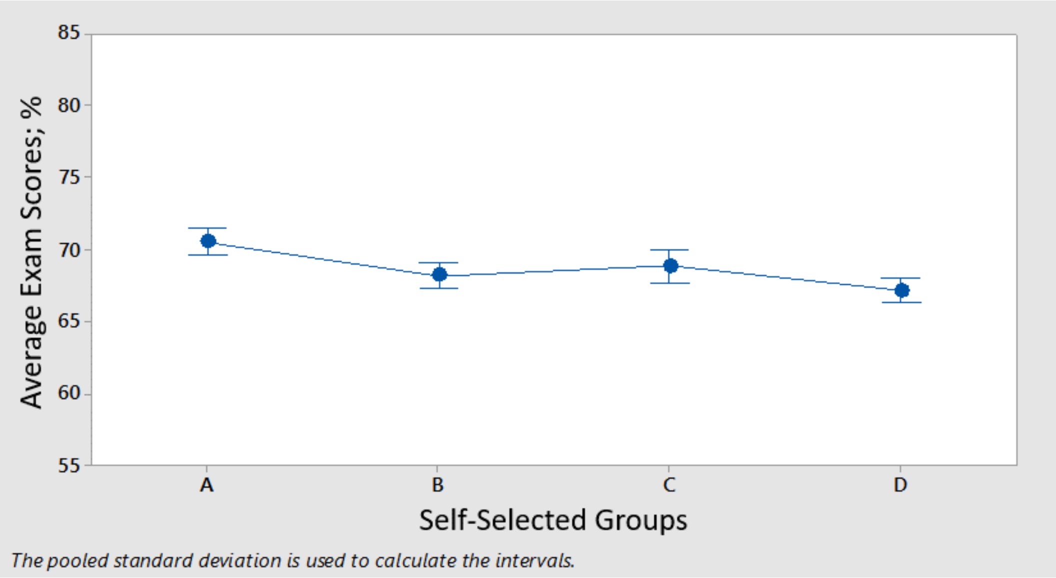


Figure 3.14. Average fall semester CHEM 1310 exam scores of self-selected groups, 2012 - 2016

Initial student preference for the online recitation option was markedly lower than that of the online lecture option, but steadily increased in preference as the study progressed. Additionally, after the three weeks sampling period students' preferences continued to increase in favor of the online recitation option. The continuing shift of student preference towards participation through an online recitation option led to a majority of students participating in CHEM 1310 through the online recitation option. This shift of preference by students serves as a strong indicator that students are becoming increasingly comfortable with online educational options. As a consequence, future enrollment increases should be easily accommodated with no need to increase physical space or personnel both of which were reduced upon implementation of this student-choice model.

Analysis of student recitation performance indicates that student performance has undergone consistent fluctuation with very few years being not significantly different. The only notable similarities between semesters appears to be for post-redesign years excepting 2013 which appeared atypically high. Through inspection of semester means, during initial years of the study, a steady drop in performance during pre-redesign years was followed by a steady increase through 2013 after which means appeared to stabilize throughout the remainder of the study. This stabilization in later redesign years along with statistical tests could indicate that the implementation of the Student-Choice model was able to reduce random effects between students of differing years.

Analysis of average exam performance through statistical tests indicated that the years studied appeared to be significantly different. Through analysis of average student exam scores, exam performance is the only student metric where students appeared to experience a detrimental effect brought on by the redesign. From the available data, it is unclear the exact cause of the performance drop. From data given in the appendix, overall student performance in the course did not seem to be adversely affected and remained consistent and generally higher in post-redesign years.

Student performance in self-selected groups of the Student-Choice model indicated that significant differences existed between some self-selected groups for both graded categories, recitation and average exam performance. Generally, data indicates a slightly higher performance for students in the fully F2F option when looking at all redesign years as a whole, but this trend is not maintained in individual post-redesign years given in the appendix. This indicates that there is no definitive advantage towards improved course performance within any of the individual course participation options present in this student-choice model. From the information presented in sections 2 and 3 related to student performance the redesign of CHEM 1310 appears to have been successful as an overall method of course delivery based on analysis of student performance. Additionally, the redesign met many of the goals laid out by maintaining course effectiveness through limited resources in addition to including more active-learning opportunities. Though further changes should be considered with the goal of improving student proficiency in the course, the Student-Choice model as implemented has shown to be an improvement over the sole use of traditional strategies previously employed.

4. LEAD REDESIGN

4.1. LEAD PROGRAM OVERVIEW

The final component of general chemistry which underwent redesign is the supplementary “Learning Enhancement Across Disciplines” (LEAD) program. LEAD is a non-mandatory student success program developed at Missouri S&T, with the aim of encouraging active-learning opportunities outside of the scheduled class time. The program started in 2001 as an introductory-physics-course learning center and grew into a campus-wide assistive instructional strategy for any course in which it was deemed beneficial. In recent years the LEAD program was implemented in over 50 courses across 15 academic departments and disciplines. For many students, LEAD has continued to be a consistent part of their college experience.

Courses taking part in the LEAD program typically offer weekly, non-mandatory student help sessions. LEAD sessions are generally facilitated by course instructors with trained ULAs as support. ULAs are chosen by the campus-wide LEAD program director based on having a minimum current overall GPA score of 3.6, and having received a letter grade of ‘A’ in the course to which they will be assigned [72]. LEAD sessions integrates aspects of both supplemental instruction [54, 55] and learning community models [48]. In keeping with the format of a typical supplemental instruction model course, instructors and ULAs are expected to monitor student progress and guide them in problem solving strategies [54].

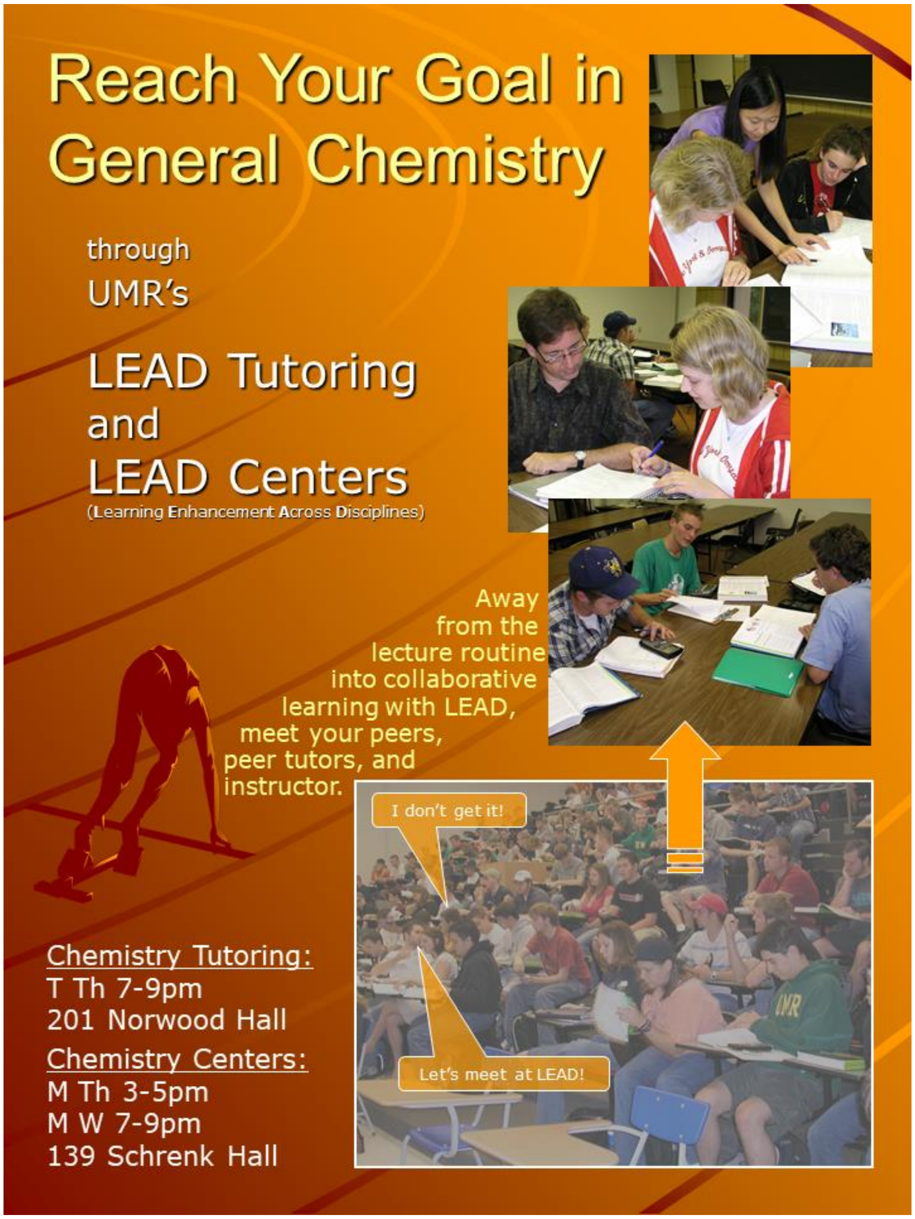
4.2. GENERAL CHEMISTRY LEAD

At Missouri S&T, one of the largest courses utilizing LEAD is the first-semester general chemistry course. As stated previously, the course is heavily comprised of non-chemistry major students (Figure 2.1) as many other majors within the university require this course. Additionally, as a gatekeeper course taken by a large population of freshmen during their first semester, it is often the first basic science course students experience at the university. Typical course enrollment exceeds 1,000 students annually with more than 80% of those students being freshmen (Figure 2.2). Many students find general chemistry to be more challenging than expected, particularly due to their lack of soft-skills such as work ethics, time management, self-reliance, persistence, and responsibility, as well as having poorly developed study habits. Additionally, incoming freshmen often spend a substantial part of their time developing new social groups and transitioning to the new demands presented by the environment of a college campus [20, 49, 50, 58]. These conditions can lead students toward experiencing substantial anxiety over a “sink-or-swim” situation, especially if there is only limited support to develop academic skills and few opportunities to improve the needed soft-skills. [24, 25, 26].

4.2.1 Initial Changes to General Chemistry LEAD. General chemistry initially implemented LEAD as an optional, supplemental-instruction style session in order to foster collaborative learning. Despite their intentions, LEAD sessions often served as a place for students to complete their online homework or other assignments, with minimal peer interaction. Because students who attended LEAD appeared to show improvement in their course performance, changes were made to encourage a larger number of students to participate. This was considered especially necessary due to the high number of first-semester, non-chemistry majors enrolled in the course who may be intimidated, frustrated, or frightened by the amount and depth of material covered in the course.

Prior to 2009, LEAD sessions experienced a fairly consistent daily attendance of around 1% of all students enrolled in general chemistry on each day sessions were offered, a participation level that was consistent with previous research into similar programs [30, 83]. To increase this rather low participation, the benefits of LEAD sessions were advertised campus-wide with large promotional posters as shown in Figure 4.1.

In addition, session attendance was strongly encouraged through multiple avenues including placement in the syllabus and announcements in-class, on the course LMS, and via course emails. Attendance was especially encouraged for those students experiencing difficulties with the course material. The number of attendances and time per attendance were tracked using a card reader; students were required to swipe their student IDs as they entered and left the room of the LEAD session. Along with student data tracking, participation was encouraged by the addition of a tangible incentive in the form of a point of extra credit which was offered for each day a student would attend a LEAD session for at least 30 minutes [84, 85]. This gave them the opportunity to earn up to 40-50 extra points, which was however less than 5% of the total points assigned in the course. During the first semester that these changes were implemented, attendance increased to around 10% of all students enrolled in the course on each day when LEAD was offered.



Reach Your Goal in General Chemistry

through
UMR's

LEAD Tutoring
and
LEAD Centers
(Learning Enhancement Across Disciplines)

Away
from the
lecture routine
into collaborative
learning with LEAD,
meet your peers,
peer tutors, and
instructor.

Chemistry Tutoring:
T Th 7-9pm
201 Norwood Hall
Chemistry Centers:
M Th 3-5pm
M W 7-9pm
139 Schrenk Hall

Figure 4.1. LEAD promotional poster

However, students attending during this initial phase of enhancement were not actively engaged and focused primarily on homework and other assignment completion.

4.2.2 General Chemistry LEAD Redesign. Subsequent changes in the General Chemistry LEAD program were implemented after three years of steadily increasing attendance. It was observed that a number of students would attend sessions only to receive the extra-credit points while not actually putting forth an effort towards improving their study skills or the mastery of the course material. Hence, in 2012, along with the beginning of the course redesign, the small-group collaboration LEAD sessions were converted into an enhanced program of peer-led problem solving and self-testing. In this enhanced LEAD format, chairs and tables were removed from the session room and replaced by chalk and dry-erase boards. Students were not permitted to use the sessions for homework completion but instead they were asked to tackle additional practice problems provided to help them master course materials. The practice problems ranged in difficulty from basic concept practice to advanced material requiring a combination of several chemical and physical theories. Because research suggested that student-student interaction strongly promotes student success, collaboration among students was encouraged for the purpose of establishing social contacts and developing communication skills [29, 75]. Due to the consistently high utilization of the program, extra credit was viewed less necessary and reduced to a maximum of about 2% of all points possible (20-30 points) but subsequently raised slightly in 2015 to a maximum of 40 total points.

The increase in LEAD attendance required more assistance, which was provided by the chemistry department through the hiring of additional ULAs. The role of these additional assistants was to aid students in approaching a problem [53] but not to lecture on chemistry or solve problems with or for the students. ULAs were selected based on their communication skills and on how well they facilitated an active-learning environment, rather than focusing on grade point averages, chemical knowledge, or the student’s major, which is typical in many supplemental instruction models and the requirements of the LEAD program [54, 55]. Weekly meetings were organized for the LEAD coordinators to discuss upcoming course material and share issues ULAs may have encountered while guiding students. In addition to ULAs, GTAs also assisted with LEAD sessions as part of the redesigned student-choice model. Implementation of the

Student-Choice model reduced the number of contact hours and responsibilities associated with their position, so assistance at 1 or 2 LEAD sessions per week became a part of the GTA position. This change gave students an opportunity to become familiar with GTAs outside of the scheduled course time, and allowed the instructor a chance to observe GTAs, as well as ULAs, and help to improve their teaching competency.

One additional small, but noteworthy change, was replacing the ID card reader affixed to the wall at the entrance of the LEAD room with a mobile swipe card reader kept by the instructor. This change was initially made to prevent students from swiping their card and garnering extra credit points without actually attending, or swiping for other students who are not attending. However, the change to a mobile ID card reader offered the additional benefits of facilitating a direct interaction between student and instructor, and providing a comfortable and casual first student-instructor contact. Anecdotally, this made both students and instructor feel more connected, which in turn may assisted with intrinsic motivation and course engagement [17].

4.3. DATA ANALYSIS AND RESULTS

Data related to student engagement with the LEAD program was tracked using a card-swipe reader and was analyzed in order to observe changes in student utilization of the program. Additional analyses were performed to determine what, if any, effect LEAD had with regards to student course performance throughout the studied years, 2009 – 2016. Finally, attendance data was related to student engagement within self-selected groups of the aforementioned Student-Choice model.

4.3.1 General Chemistry LEAD Redesign. Yearly attendance data was further divided into subsets based on a range of attendances and given in terms of the percentage of students attending a given range as shown in Table 4.1. During the initial semester of implementing the extra-credit incentive for participation (2009), 58% of students attended at least one session, with 27% of students participating in five or more sessions. Five LEAD sessions is equivalent to one week of attendances or one attendance per written exam. Student participation at sessions experienced a near continual increase, Table 4.1 and Figure 4.2, to a maximum of 86% students attending at least once by 2014.

Table 4.1. Yearly fall semester student CHEM 1310 LEAD session attendance

Year	Attended LEAD (%)	0 (%)	1 – 4 (%)	5 – 9 (%)	10 – 14 (%)	15 – 20 (%)	> 20 (%)
2009	58.8	41.2	31.2	12.0	4.3	2.9	8.4
2010	68.5	31.5	29.4	12.3	5.7	6.3	14.8
2011	70.9	29.1	28.1	13.7	9.6	7.2	12.4
2012	78.6	21.4	28.9	17.3	9.3	6.5	16.6
2013	78.0	22.0	31.5	18.7	11.3	8.7	7.6
2014	86.4	13.6	34.6	20.4	10.7	10.2	10.6
2015	75.8	24.2	43.3	15.0	7.6	4.3	5.6
2016	78.3	21.7	37.9	14.9	7.4	7.4	10.8

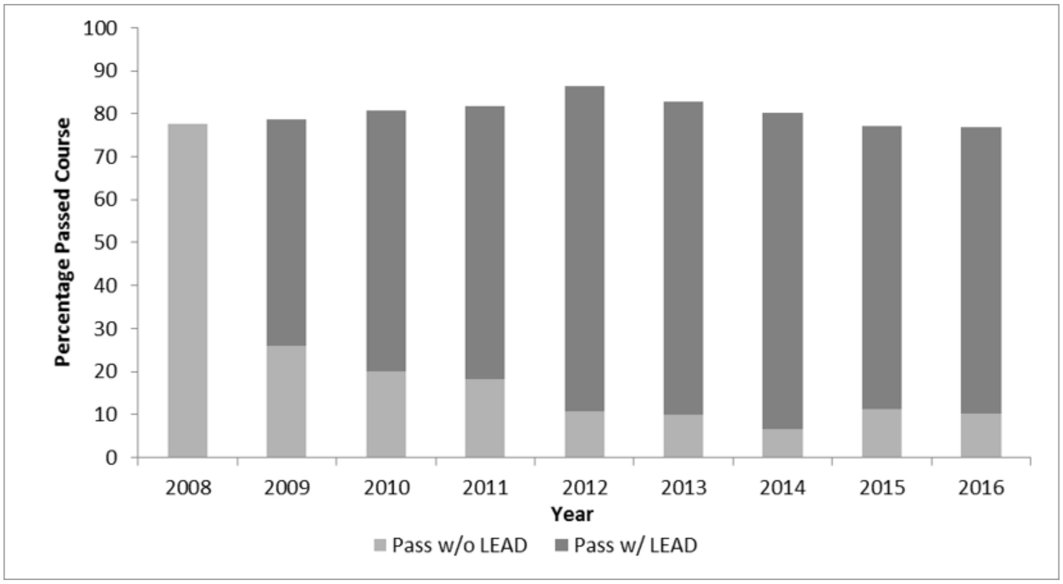


Figure 4.2. Students with a passing grade in fall semester CHEM 1310 based on LEAD participation

4.3.2 LEAD and Student Performance. In addition to attendance of LEAD sessions, the impact of LEAD on student learning and performance was analyzed in multiple ways. An initial analysis of the pass-fail rate in Figure 4.2 shows that changes in the program did not significantly change the pass-fail rate in the course.

To determine if relationship existed between overall performance in the course and LEAD attendance, average attendances were compared to final CHEM 1310 course letter-grades. This relationship, shown in Figure 4.3, does not include students who had zero LEAD attendances.

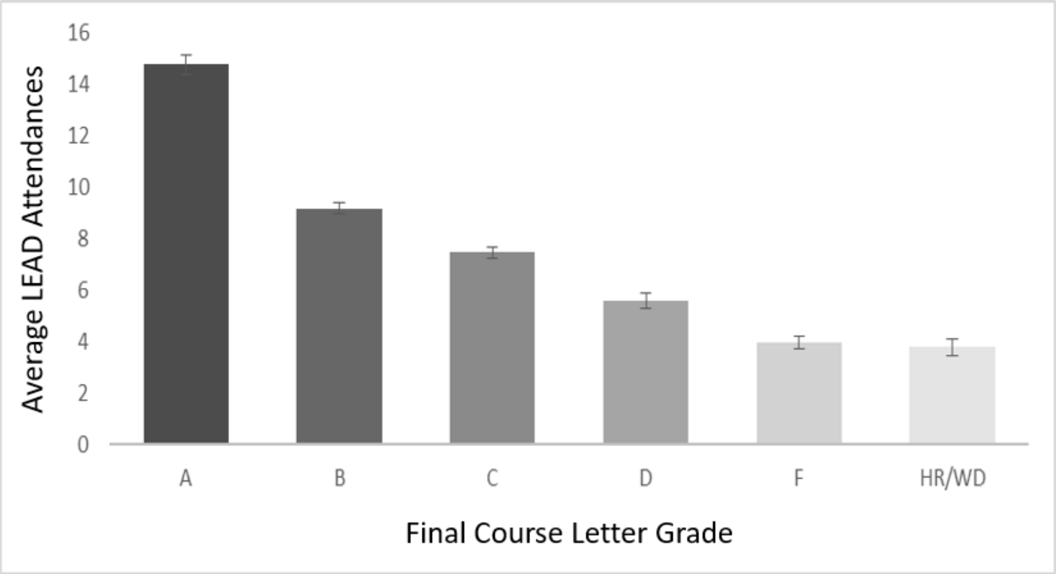


Figure 4.3. Average LEAD attendance by final fall semester CHEM 1310 letter grade

This comparison of average LEAD attendance with overall letter-grade in the course indicates a relationship between student success and LEAD participation. In order to further determine whether LEAD attendances seemed to influence student success in the course, overall CHEM 1310 course grades were compared to the number of LEAD attendances (see Figure 4.4). Figure 4.4 also indicates the standard deviation (gray lines) around each number of attendances starting at 14 attendances, equivalent to one LEAD participation per week. Data relating grades to LEAD attendance become less reliable at higher number of attendances as fewer students participated this often.

It is noteworthy that even with low participation student performance already improved substantially. At the one attendance per week the standard deviation of the average final score (gray lines in Figure 4.4) predicts a passing grade even for lower performing students. Additional analysis of the data shows that for zero attendances the median percentage score was 5% lower than the average percentage score. For students attending 10 or more sessions, the average and median percentage scores coincide.

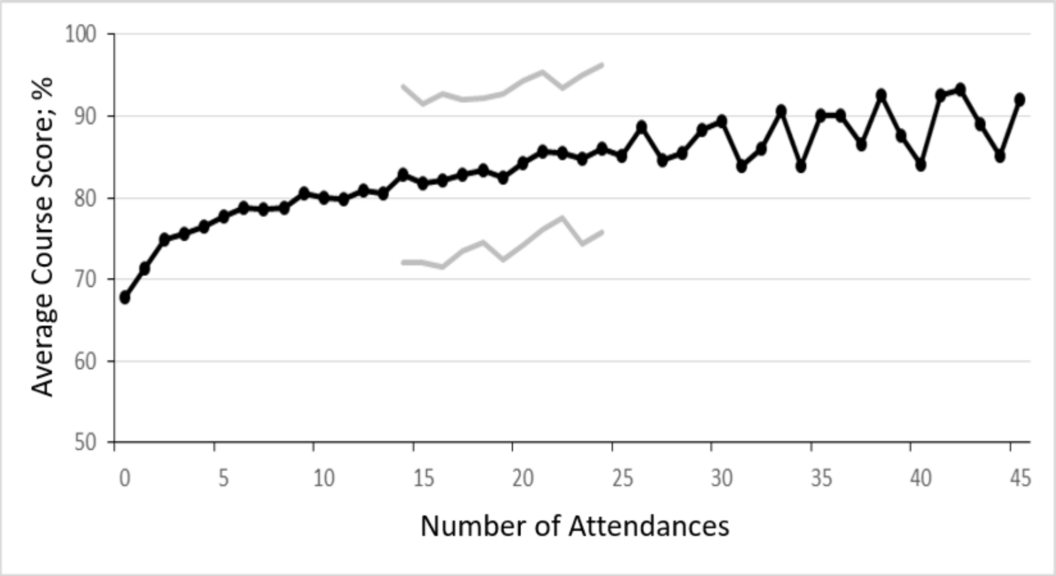


Figure 4.4. Average fall semester CHEM 1310 percentage score based on number of LEAD attendances

4.3.3 LEAD and Student Performance of Self-Selected Groups. In order to determine any effect of LEAD attendance as relates to the implemented Student-Choice model attendance and performance were both observed for each of the self-selected groups, A, B, C, and D. An initial chart of average student attendance based on self-selected group can be seen in Figure 4.5.

From the chart, it can be seen that students participating in F2F lecture options, groups A and C, tend toward a higher LEAD attendance versus those participating in the online lecture. It was also of interest to determine if there was a relationship between LEAD attendance and grades within self-selected groups as appears to be the case for the general course population. In order to determine if this was true, average final course percentages were compared for students in each group based on whether or not they participated in LEAD (Figure 4.6). Similar to the outcomes shown for students in Figures 4.2 and 4.5, Figure 4.6 indicates that students participating in LEAD sessions exhibit higher performance than those students who do not attend.

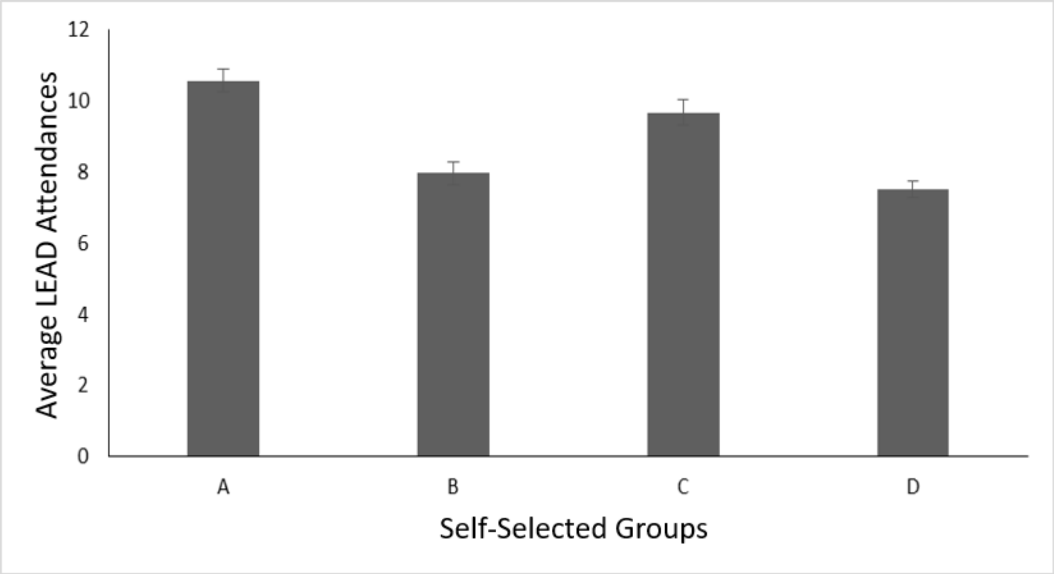


Figure 4.5. Average fall semester CHEM 1310 LEAD attendance for each self-selected group of the Student-Choice model

4.4. SUMMARY

The LEAD program at Missouri S&T has a longstanding tradition of assisting students in their academic development and success. Measures to increase participation in the general-chemistry LEAD sessions included strong campus-wide promotional advertising and a tangible incentive and were highly successful. After advertising and addition of the extra-credit incentive, student participation in LEAD experienced consistent increases through 2012 reaching an attendance high in 2014. Notably, the subsequent reduction in the extra-credit offering did not result in a decrease in attendance. Similarly, the later incentive increase in 2015 did not lead to an increase in attendance, but actually a drop in attendance is noted in 2015 and later years. These fluctuations in attendance as relates to changes in available extra points seem to indicate that student participation no longer depends on extra-credit incentives but rather on general changes in the LEAD operation.

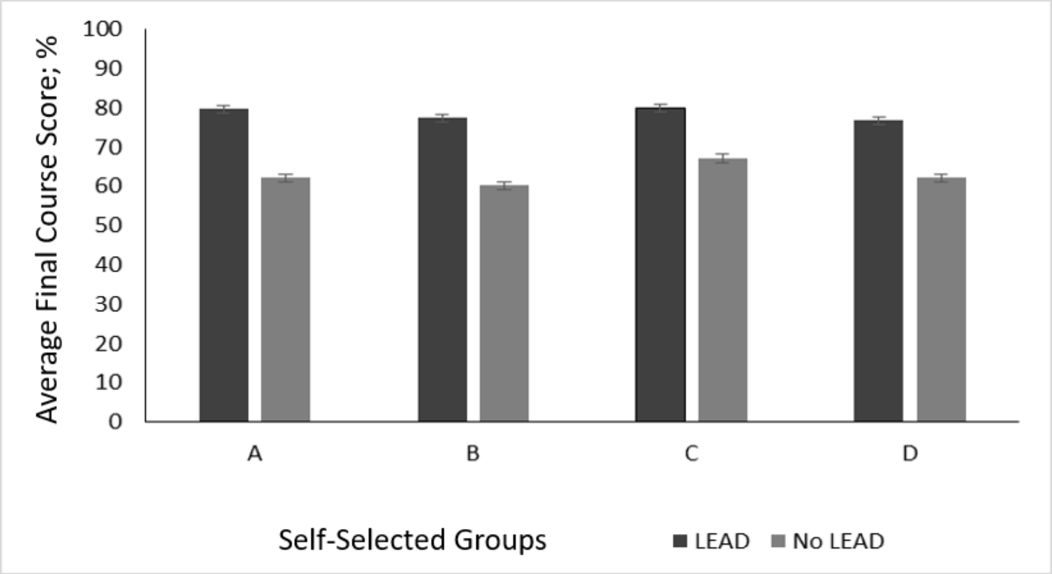


Figure 4.6. Average final course score for fall semester CHEM 1310 students in each self-selected group based on LEAD attendance

The first drop in attendance corresponded with the full change from traditional, study-hall sessions to an enhanced, active problem-solving model. The second change in 2015 corresponded with a change to how students were initially awarded LEAD points. This drop may ultimately be attributed to students showing an aversion to changes in teaching and learning styles. In both cases however, after the initial year of a change, attendance recovered and continued to increase. This indicated that students adjusted well to changes and generally appreciate the benefits of peer-led learning. All of this taken together indicates there is no need to offer more than a minimum tangible incentive or return LEAD back to a session where students come to take home a tangible product such as the completion of their mandatory homework or other assignments.

The pass rate for the course, indicates that LEAD attendance does not significantly impact student course performance from year to year due to the appearance of only small, tentative gains. Alternatively, LEAD attendance does seem to have a relationship with student success making it appear to be a valuable assistive instructional tool for maintaining student success both pre- and post- implementation of the Student-Choice model. Based on the nature of LEAD attendance as a voluntary student program, it remains difficult to prove the effectiveness of the LEAD program, but the apparent relationship between participation and student success should not be overlooked.

While data does not definitively verify the effectiveness of LEAD as a program, it is important to note the strong potential role LEAD has in promoting the university as a community of learners and in assisting students, particularly those new to the university in developing skills for success. LEAD sessions can be used to provide for a common location where students can practice and master course material, while simultaneously offering increased student-student and student-instructor interactions. LEAD also gives instructors a unique opportunity to identify issues students encounter with the material on a larger scale rather than assisting them individually. Additionally, while there are no definite indications that LEAD is a strong influence on student performance, attendance data from this non-mandatory program could potentially serve as a predictor for student success. It is expected that when this data is combined with other quantitative data, such as homework assignment submission and class attendance, it could become an effective early identifier of students prone to failure in the course while also serving as a strong remediation tool.

5. SPRING SEMESTER GENERAL CHEMISTRY

5.1. LEAD PROGRAM OVERVIEW

Earlier sections of this dissertation focused exclusively on the effect of the course redesign on performance outcomes for students enrolled in fall semester offerings of CHEM 1310 at Missouri S&T. During the fall semester the methodologies employed, demographics, general technical aspects (number of instructors and sections) remained relatively consistent within pre-redesign semesters and again during post-redesign semesters. While fall offerings of CHEM 1310 were generally consistent and divisible into pre- and post-redesign categories, the spring semester offerings were not. Spring semesters of CHEM 1310 underwent more changes during pre-redesign semesters, had a much smaller size and a fluctuating number of instructors. Additionally, spring CHEM 1310 students were anecdotally considered to be on average weaker performing when compared to fall semester students. Due to these technical incongruities and the assumptions related to spring CHEM 1310, it was necessary to analyze the spring semester separate from the fall. Analyzing performance outcomes during the spring semester of CHEM 1310 independently also allows for trends present in the fall to be compared with those identified during the spring.

5.2. SPRING SEMESTER CHEM 1310 AT MISSOURI S&T

As stated previously, CHEM 1310 is a typical gatekeeper course with the major enrolled cohort being freshman/non-chemistry majors. During the fall semester, typically four main lecture sections accommodate between 750 – 900 students. Yearly freshman enrollment exceeds that with approximately 1500 students enrolling each fall semester. This high enrollment along with a limited fall capacity can inhibit many students from taking the fall semester offering of CHEM 1310. For those students that are unable to enroll in the fall semester, or those encouraged to not take the course due to low math placement scores, a spring semester CHEM 1310 offering has remained consistently available at Missouri S&T.

5.2.1 Spring Demographics. As would be expected, the spring semester offering of CHEM 1310 shares demographic similarities with the fall semester, though with notable differences. While spring CHEM 1310 still consists of a freshman majority, this group's size is reduced by approximately 15% from that shown in the fall (Figure 2.1) with all other academic levels being increased (Figure 5.1).

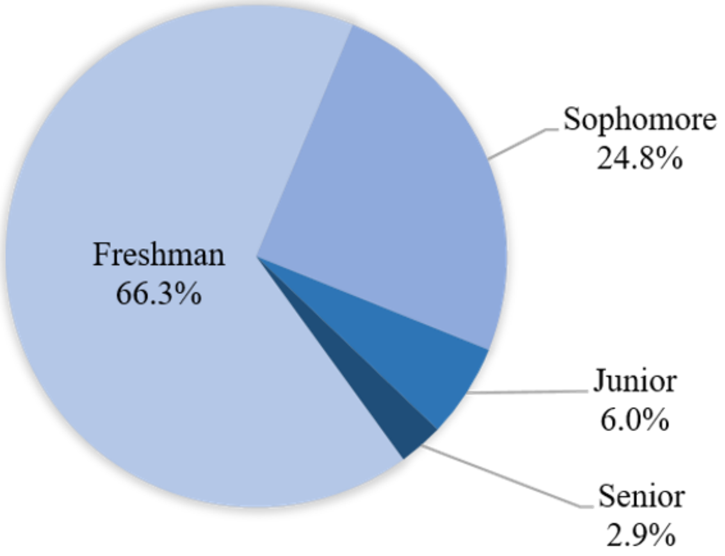


Figure 5.1. Academic level of students enrolled in spring semester CHEM 1310 from 2012 - 2017

While academic levels were different from fall to spring, the composition based on student majors in spring CHEM 1310 (Figure 5.2) remained nearly identical to that shown during the fall semester (Figure 2.2).

5.2.2 Spring CHEM 1310 Prior to Major Course Redesign. At the beginning of this study, there was only a single CHEM 1310 lecture section available each spring semester. Enrollment for this section was generally between 180 – 200 students, similar to that of one individual fall section during the same period. Students met for three, one-hour lecture sessions each week which used clicker support. A weekly, one-hour GTA-led recitation session was also operated but required only eight sections to accommodate all students. Spring CHEM 1310 also used the same LMS, online homework system, and discussion board to manage the course as the fall course. LEAD sessions were also held during the spring semester, but initially there were only two held per week as opposed to the four per week of the fall. Another dissimilarity to the fall semester experience was the offering of extra credit opportunities through extra credit questions and quizzes during all years of the study with later years becoming more aligned to the fall LEAD participation based extra credit.

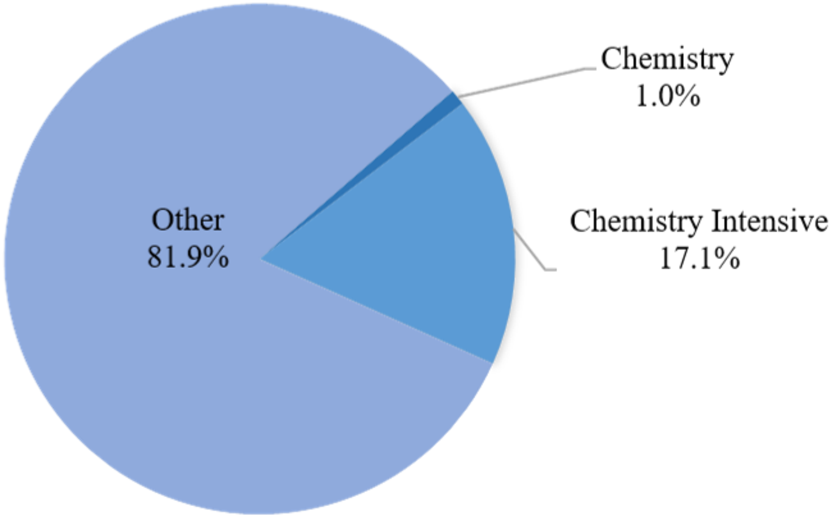


Figure 5.2. Majors of students enrolled in spring semester CHEM 1310 from 2012 – 2017

As stated, spring CHEM 1310 had multiple distinct periods where change had occurred. The first of these changes occurred in 2010 with the addition of a second lecture section led by a different instructor. The additional section of CHEM 1310 allowed for more students to be accommodated, an action necessary due to increasing enrollment. Addition of a second section made it necessary for the two sections to adopt common standards in order to provide a similar experience for enrolled students regardless of section. These new standards had the additional effect of more closely aligning the spring course to that of the fall experience.

Initial implementation of the redesign course model occurred during the spring 2012 semester, however it was not a full implementation, but a trial to test the viability of all components and identify any potential issues prior to full implementation in the fall 2012 semester. For this trial implementation, two sections existed, with one cohort acting as a control, following the fully traditional model already in use. The other cohort acted as the treatment cohort and was split into the four redesign groups referenced earlier (Figure 2.4). In order to maintain ethical standards of conduct, both cohorts were given full access to all available resources. The number of available LEAD sessions was increased to match that of the fall semester in 2011 and remained consistent with that of the fall LEAD program availability. Additionally, both cohort sections had a common instructor who also led fall semester courses which helped to further aligning the fall and spring semester courses. During this trial semester of the redesign, students in the treatment cohort were given an initial choice of F2F or online lecture and recitation for their course experience. The mandatory sampling rotation was not used since one requirement of the redesign was to maintain approximately equivalent student enrollment in F2F and online options.

The final major change to the spring semester CHEM 1310 happened in 2013 when the Student-Choice model was fully implemented for the spring semester course. This included the mandatory, three-week sampling period along with the option for students to change their course experience. After full implementation, the fall and spring semesters were fully equivalent in both standards and scope, with both semesters covering an increased number of topics relative to previous semesters. LEAD sessions had become an active practice focused with students no longer passively working on assigned work.

5.2.3 The Major Spring Course Redesign, 2012 – 2017. As part of the major course redesign initiative that started in 2011, the 2012 spring semester offering of CHEM 1310 was the first semester to move beyond testing new resources and begin testing the redesign options being offered including reduced lecture time, more active recitation, and online options for both lecture and recitation.

As part of the full Student-Choice model implementation which occurred after spring 2012, various technical changes were made. The more rigid enrollment available for students regarding the available course experience options (F2F, online, or hybrid) was changed so that students could make an informed choice based on a mandatory sampling rotation. For F2F recitations, during the initial semester, students worked together in groups of four students to collaboratively practice and solve an assigned recitation packet. It was observed that in these larger groups, some students tended to lose focus and not actively participate. In later semesters, student groups were reduced to 2 students per group. An additional issue related to the larger groups was the effective delivery of group quizzes during the partial implementation. Collaborative groups were allowed to take a shared quiz. This practice led to weaker and less active students becoming overly reliant on stronger students for their grade. In later semesters, active participation was motivated through individual quizzes which served to maintain student accountability. A final change from the initial recitation redesign was the elimination of a peer survey. It was originally thought that by having each student rate the participation and contribution of other students in their collaborative group for a small incentive, each student would be more motivated to fully participate. Many students did not fill out the survey while others did not appear to fill it out objectively. As a consequence, this led to its discontinuation in favor of smaller groups and individualized quizzing.

In order to successfully facilitate the more active F2F recitations and LEAD sessions after full implementation of the Student-Choice model, it was necessary to recruit ULAs. Initial students brought in as ULAs were recruited heavily from the 2012 spring semester of CHEM 1310 due in part to their familiarity with the newly implanted model. These students were recruited as ULAs not only because their experience with the redesign, but also because of having strong communication and problem-solving skills which were more easily identified through the active collaborative approaches employed as part of the redesign.

5.3. DATA ANALYSIS AND RESULTS

Collected data on student grade categories was analyzed using the same statistical methods as those shown in sections 2 - 4. Unlike the fall semesters of CHEM 1310, which can be readily divided into two major time periods, pre- and post-redesign, during the spring semesters there were multiple instances where operation of the course underwent changes. The first major change was the addition of a second section and instructor of CHEM 1310 where previously there had been only one independently instructed section. This change, brought about to accommodate enrollment increases, required the two sections to become aligned with one another similarly to how the fall semester sections of CHEM 1310 were operated. The next major change involved the first year of partial redesign implementation in 2012. During this partial implementation, one section was operated in the fully traditional format which included three, one-hour lectures and a one-hour recitation each week. The other section was divided into the four redesign groups represented in Figure 2.4 and met for two hours of lecture each week in addition to choosing either a two-hour F2F recitation or an online recitation. While both the traditional and redesign course sections were operated differently, both covered the same topics and had access to the same resources including the recorded lectures of the redesign section. Unlike all other semesters, data analysis of the 2012 spring semester could not be performed in any meaningful way due to the high variances of enrollment between the traditional and redesign sections (A-D). The final major change occurred in 2013 with the full implementation of the redesign in its current form as a student-choice model. It is necessary to account for these major changes in order to get a better accounting of the effects observed. In order to homogenize the data presented below with the fall data, spring semester data focus was kept in line with the consideration of two main time periods, pre-redesign (2008-2011), and post-redesign (2013-2016). The 2012 spring semester has components which align it with both the traditional and redesign models, but the small sample sizes of the traditional, and much smaller individual redesign groups (A-D) prohibit it from being fully analyzed as part of either group.

5.3.1 Student Preference 2013 – 2017. Upon full implementation of the Student-Choice model in spring 2013, CHEM 1310 students had the opportunity to experience all available lecture and recitation options through the mandatory sampling rotation first used in the previous fall. Spring semester lecture preference shared similarities with that observed in the fall semesters (Figures 2.5 – 2.9) of CHEM 1310 with a majority of students initially enrolling in F2F lectures, though to a much higher percentage. Also, similar to the fall semester, after the sampling period students switched more heavily to the online lecture section as opposed to the very low percentage that switched from online to F2F. Unlike the fall semester student preference data, students in the spring semester appeared to be more extreme in switching of preference as well as initial and final preference all of which is indicated in Figures 5.3 – 5.7.

Student preference for recitation, shown in Figures 5.8 – 5.12, was also initially very similar to that of observed during the fall semesters (Figures 3.1 – 3.5). After the full implementation, a majority of students began the semester enrolled in F2F recitation. After the sampling period students also generally switched far more heavily into the online recitation section than into the F2F offerings similar to what was observed in the fall semesters.

The final combination selected by students and general trend of student choice for course participation is indicated in Table 5.1. Similar to what was observed during the fall semesters, over time the fully online section continued to increase. The fully F2F did not consistently decrease in population, but it did appear to be trending in that direction. The hybrid course options, B and C, maintained a relatively consistent percentage population of students similar to that observed during the fall semesters.

5.3.2 Comparison of Student Performance Pre- and Post-Redesign.

Effectiveness of the redesign methods was analyzed using the same methods used for the fall semester data. One-way ANOVA and Tukey post-hoc analyses were performed on all student grade categories previously discussed including clicker, homework, recitation, exam average, and overall percentages. In order to simplify the analysis and more cohesively relate changes to student performance in the spring with that of the fall, data presented will be focused on overall course performance with all other categories available in the appendix. One-way ANOVA using student overall course percentage as a response and year as the factor was performed and indicated a rejection of the null hypothesis [$F(8,1839) = 51.73$, $p < 0.001$]. The size of the effect was indicated as medium based on an $\eta^2 = 0.06$. Tukey post-hoc (Figure 5.13) further elaborated that, of the years studied the post-redesign years did not appear to have significant differences with each other.

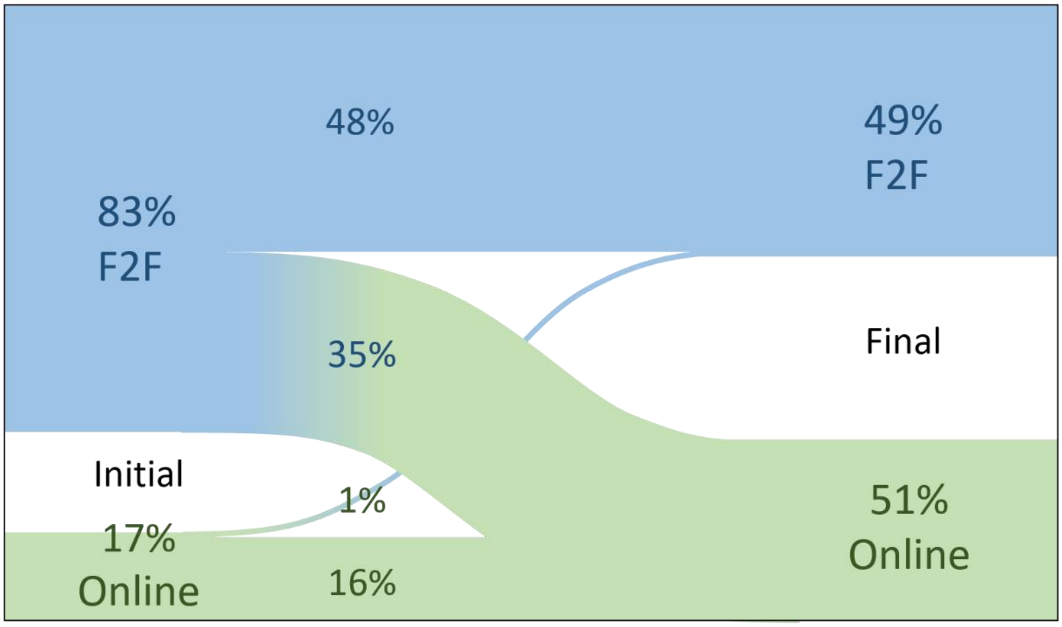


Figure 5.3. Student lecture preference, 2013

Pre-redesign years did appear to be significantly different from one another in addition to being significantly different from the post-redesign spring semesters.

Changes to overall student course performance are shown in Figure 5.14. The plot indicates that during the pre-redesign years, spring semester CHEM 1310 student performance generally declined as the course became more aligned with the fall semester.

Spring 2012 appears atypically high relative to all other years which could be due to the operation of an additional, traditional section along with the extra resources developed for the redesign sections including online lecture recordings. It is important to note that the atypically high spring 2012 CHEM 1310 sections correspond to the fall 2011 semester which also had higher student performance than previous fall semesters (Appendix data). Student course performance during post-redesign spring semesters of CHEM 1310, while not higher than pre-redesign semesters did appear to remain stable.

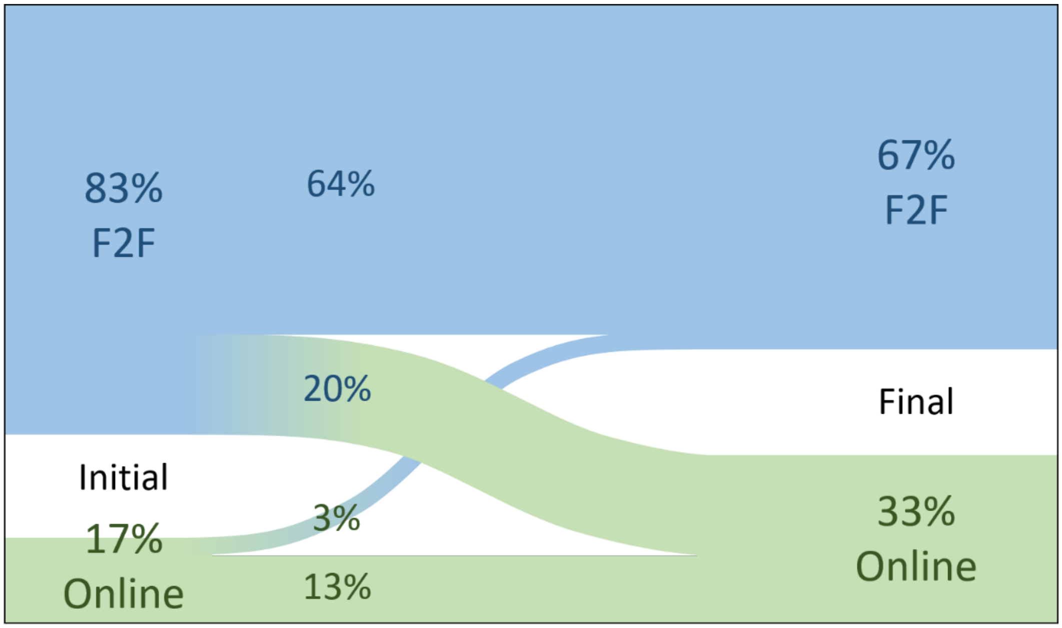


Figure 5.4. Student lecture preference, 2014

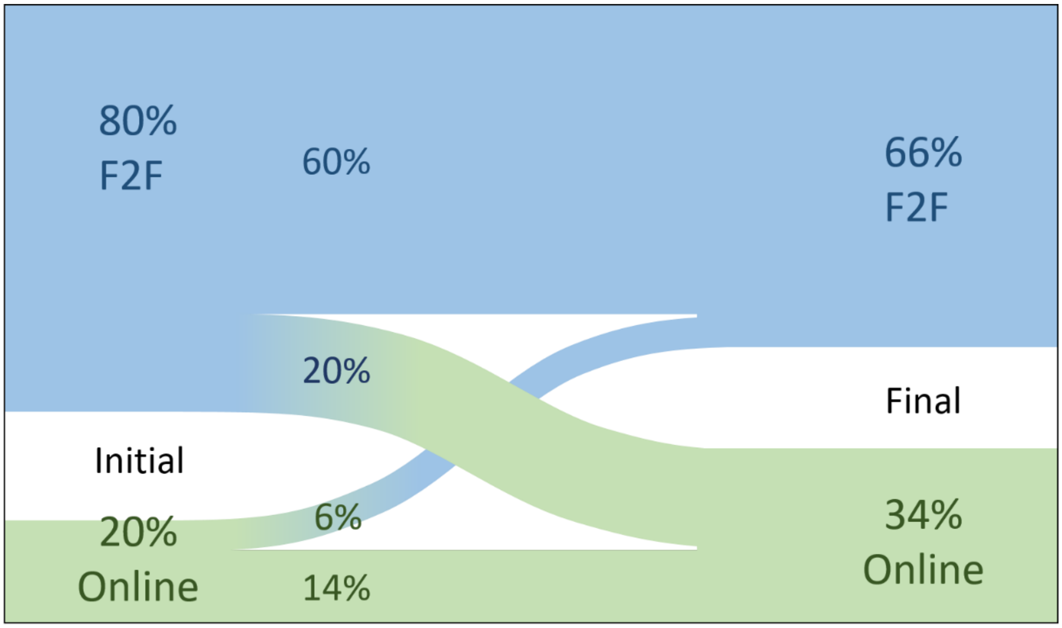


Figure 5.5. Student lecture preference, 2015

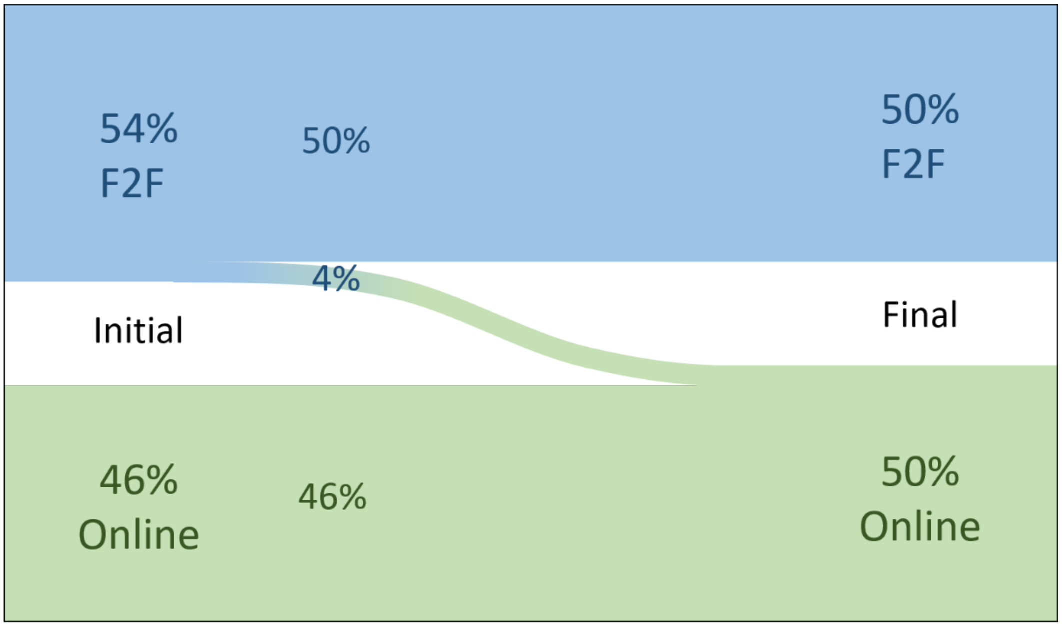


Figure 5.6. Student lecture preference, 2016

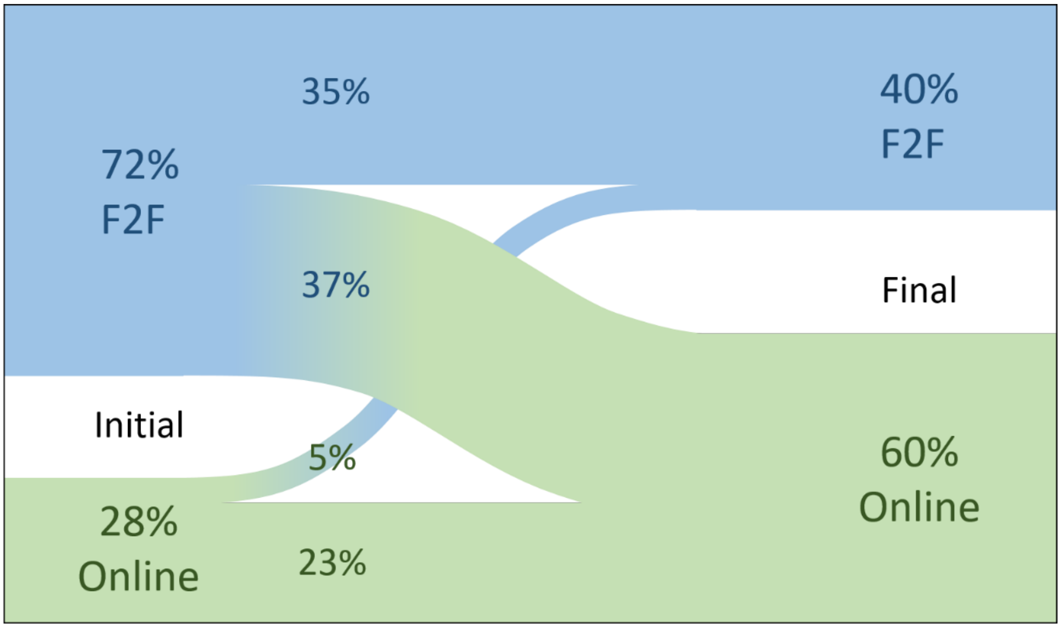


Figure 5.7. Student lecture preference, 2017

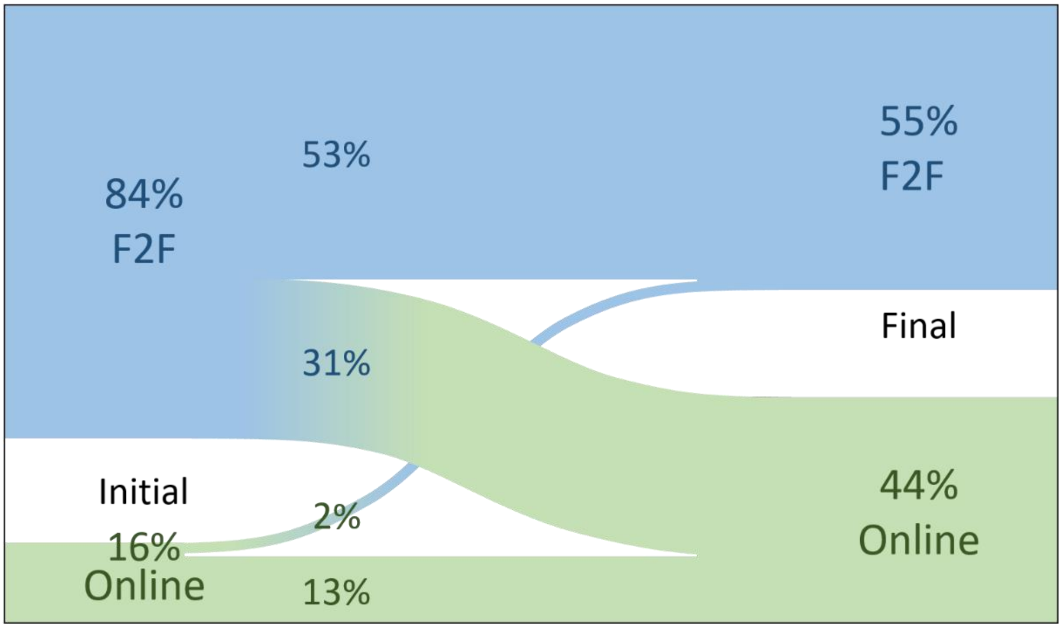


Figure 5.8. Student recitation preference, 2013

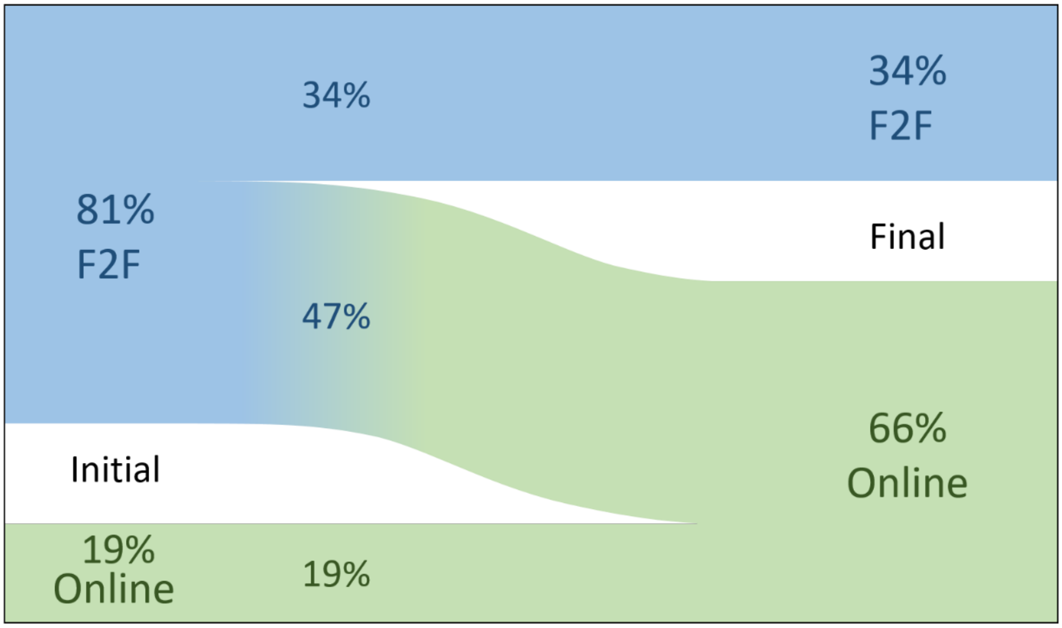


Figure 5.9. Student recitation preference, 2014

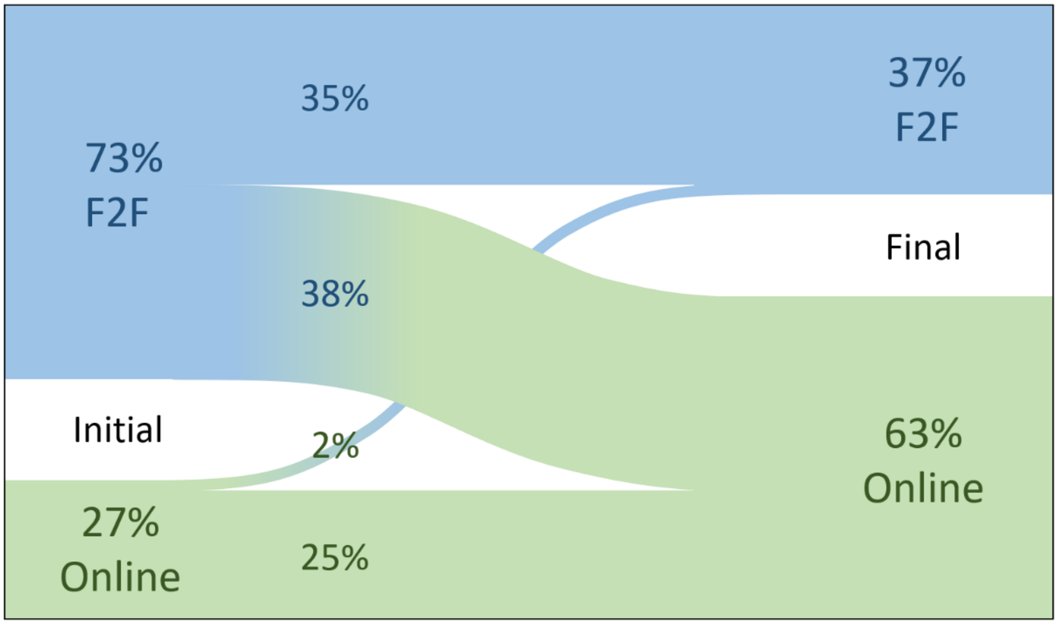


Figure 5.10. Student recitation preference, 2015

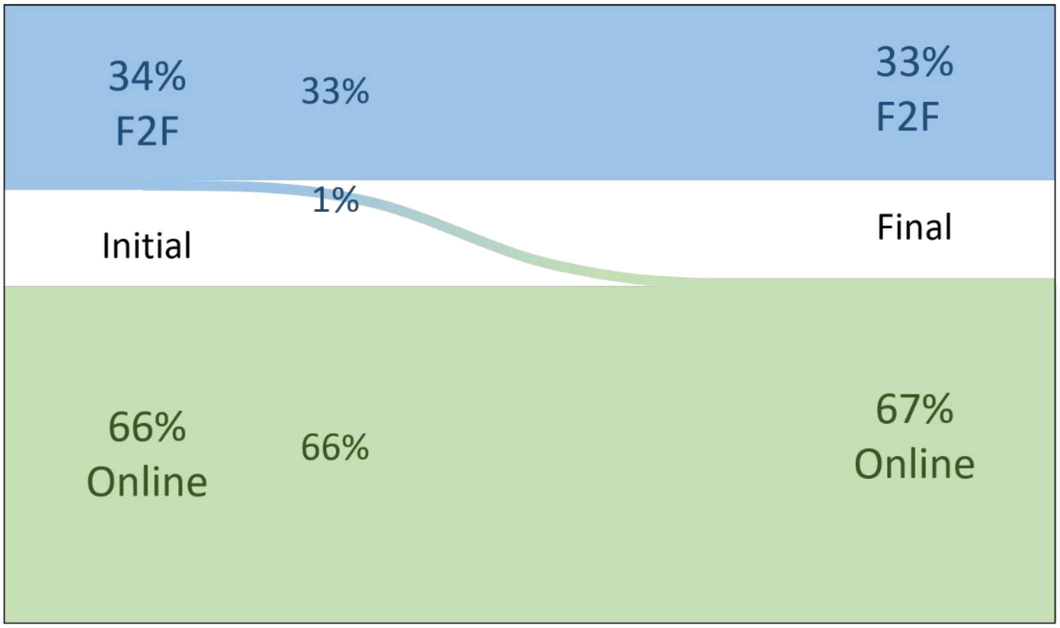


Figure 5.11. Student recitation preference, 2016

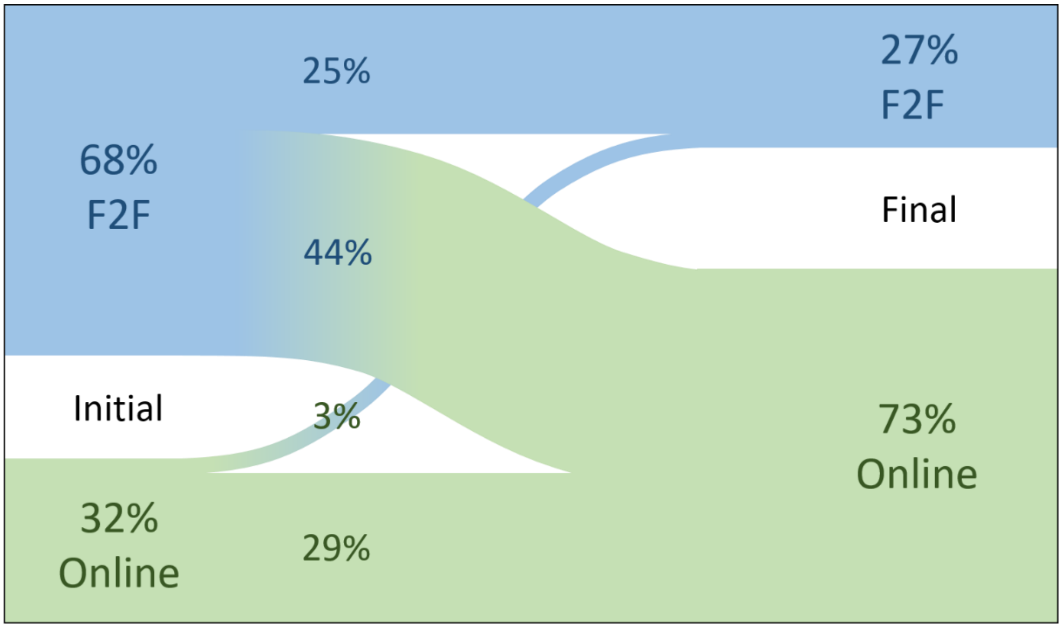


Figure 5.12. Student recitation preference, 2017

Table 5.1. Final student preference of spring semester Student-Choice model participation

Spring Semester (Enrolled Students)	Self-Selected Groups % A	% B	% C	% D
SP 2013 (N = 176)	32.4	23.9	16.0	27.8
SP 2014 (N = 228)	23.2	7.9	44.7	24.1
SP 2015 (N = 194)	31.4	9.8	33.0	25.8
SP 2016 (N = 236)	23.3	9.75	28.8	38.1
SP 2017 (N = 252)	11.9	19.8	20.6	47.6

As part of the spring data analysis for CHEM 1310 it is important to relate the spring semester performance to that of the fall semester. Anecdotally, students were considered to be academically weaker in spring compared to students taking the course in the fall. As shown previously, there are demographic differences in addition to differences observed in student preference. Additionally, as the course moved from independent instruction to collaborative instruction in a method similar to that offered in the fall it was important to note whether a difference between spring and fall semester CHEM 1310 student performance existed. A plot of overall course scores, shown in Figure 5.15, tends to indicate that there may indeed be performance differences between the semesters.

5.3.3 Analysis of Self-Selected Groups. Further analysis was performed on the years after full implementation of the Student-Choice model to determine if any significant differences existed between the different self-selected groups represented in Figure 2.4. One-way ANOVA and Tukey post-hoc using a response of overall student course percentages with self-selected groups (A, B, C, and D) as a factor.

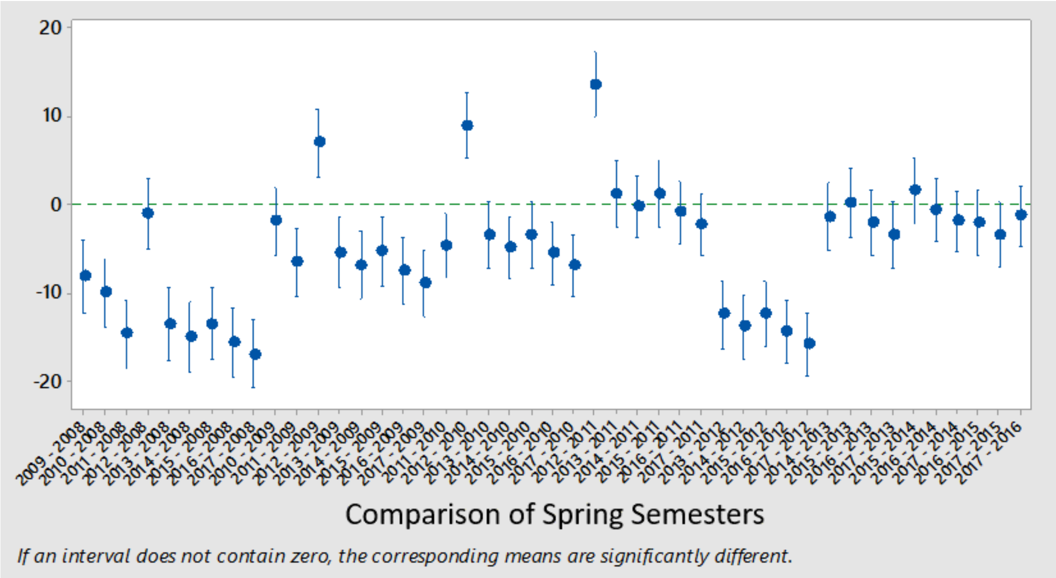


Figure 5.13. Tukey interval plot for overall student percentage from 2008 – 2017

Similar to the fall data analyzed, one-way ANOVA of student course percentages failed to reject the null hypothesis [$F(3,833) = 1.61$, $p < 0.187$] indicating that no significant differences existed between students in self-selected groups. This outcome is further shown by a plot of overall student scores for each self-selected group shown in Figure 5.16.

Further information relating data for the spring semesters of the redesign are included as appendices.

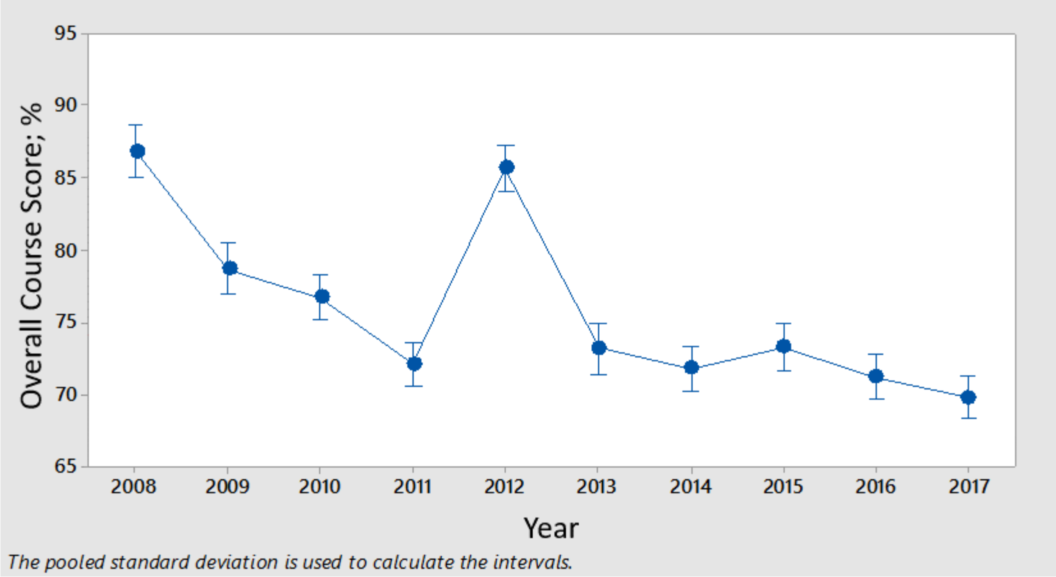


Figure 5.14. Mean overall student percentage scores from 2008 – 2017

Data includes one-way ANOVA outputs along with Tukey post-hoc plots, and mean plots for all discussed grade categories (clicker, homework, recitation, exam, and overall course scores) for each individual year of the redesign with self-selected groups as the factor.

5.3.4 Spring Semester LEAD. Spring semester CHEM 1310 LEAD attendance data was divided into subsets in the same fashion as the data for fall semester LEAD attendance (Table 4.1). For the initial spring semester where LEAD data was tracked and an extra credit incentive was available, overall LEAD attendance was lower than that of the fall with 52% of students attending at least one session during the semester.

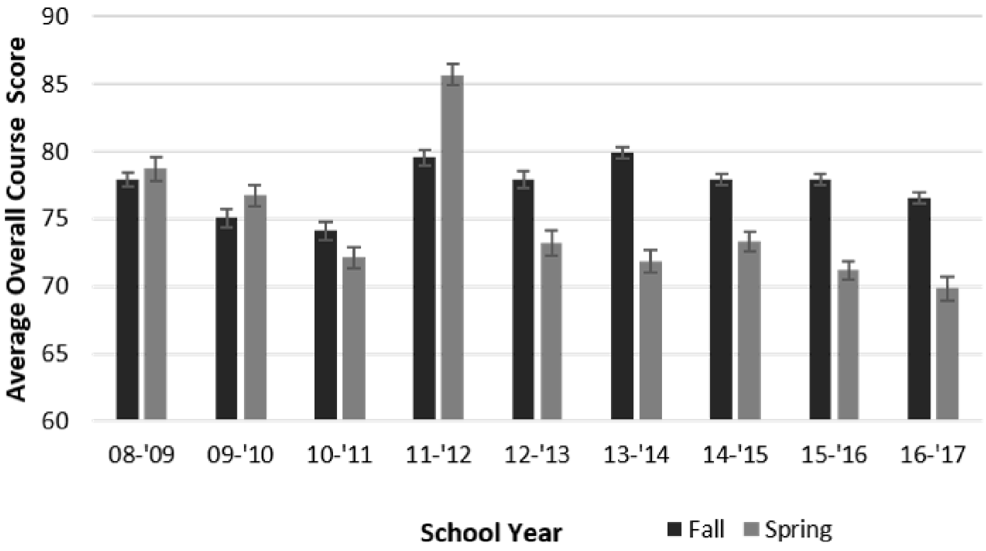


Figure 5.15. Overall course performance for fall and spring semesters during each academic year

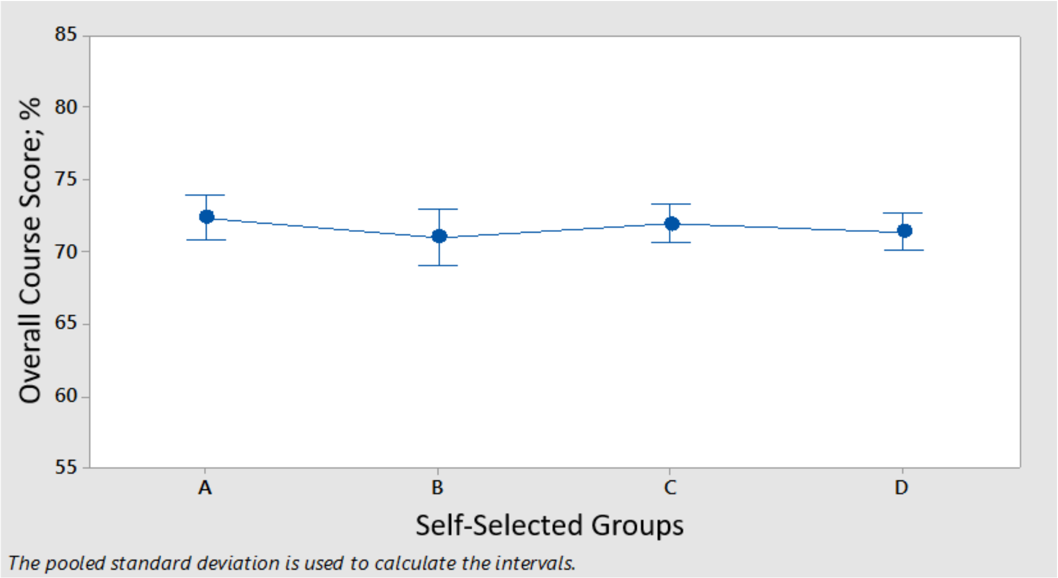


Figure 5.16. Overall course scores for self-selected groups during years of spring fully implemented redesign

The percentage of students attending five or more sessions was 38%, higher than that of the previous fall 2009 semester. Where fall semester LEAD attendance continued to increase, spring LEAD attendance remained consistently lower reaching maximum attendance in the 2012 semester and dropping back to approximately 50% attendance in later semesters.

In order to determine if any relationship existed between LEAD attendance and student pass rate, the percentage of students passing the course was determined for each year (Figure 5.17).

The percentage of students with a passing course grade in CHEM 1310 continued to fluctuate and remained generally lower than that of the fall semesters regardless of LEAD attendance. In the majority of spring semesters where LEAD attendance was tracked, a higher percentage of passing students participated in LEAD. This changed in the last two years of the study with a higher percentage of students earning a passing score while not having attended LEAD.

Table 5.2. Yearly spring semester student CHEM 1310 LEAD session attendance

Year	Attended LEAD (%)	0 (%)	1 – 4 (%)	5 – 9 (%)	10 – 14 (%)	15 – 20 (%)	> 20 (%)
2010	52.8	47.2	14.3	10.9	8.7	6.8	12.1
2011	69.1	30.9	20.4	14.4	6.7	8.4	19.3
2012	76.8	23.2	19.3	8.6	6.0	9.0	33.9
2013	63.5	36.5	19.4	9.1	8.7	8.4	17.9
2014	58.9	41.1	27.4	11.5	9.2	5.7	5.1
2015	48.9	51.1	20.8	12.3	6.3	6.0	3.5
2016	50.4	49.6	18.1	10.2	5.5	7.9	8.7
2017	58.7	41.3	27.0	11.9	6.0	4.8	9.1

Average LEAD attendances were determined for each course letter grade in order to establish whether a similar relationship existed for spring semester CHEM 1310 LEAD attendance to that observed in the fall.

A plot of average LEAD attendances per letter grade given in Figure 5.18 and does not include students who did not participate in LEAD sessions. While the same general relationship was found to exist with higher letter grades corresponding to more LEAD attendances, the average number of LEAD attendances associated with each letter grade were increased relative to those observed for the fall.

The same general relationship was found to exist in spring and fall semesters of CHEM 1310 with higher letter grades corresponding to more LEAD attendances. In contrast to the fall semester, the average number of LEAD attendances associated with each letter grade were increased. The increase in LEAD attendances per letter grade in Figure 5.18 when taken in conjunction with the lower overall pass rate and lower LEAD attendance in general represented in Figure 5.17 and Table 5.1 could corroborate the hypothesis that spring semester students are lower performing when compared to students in the fall semester.

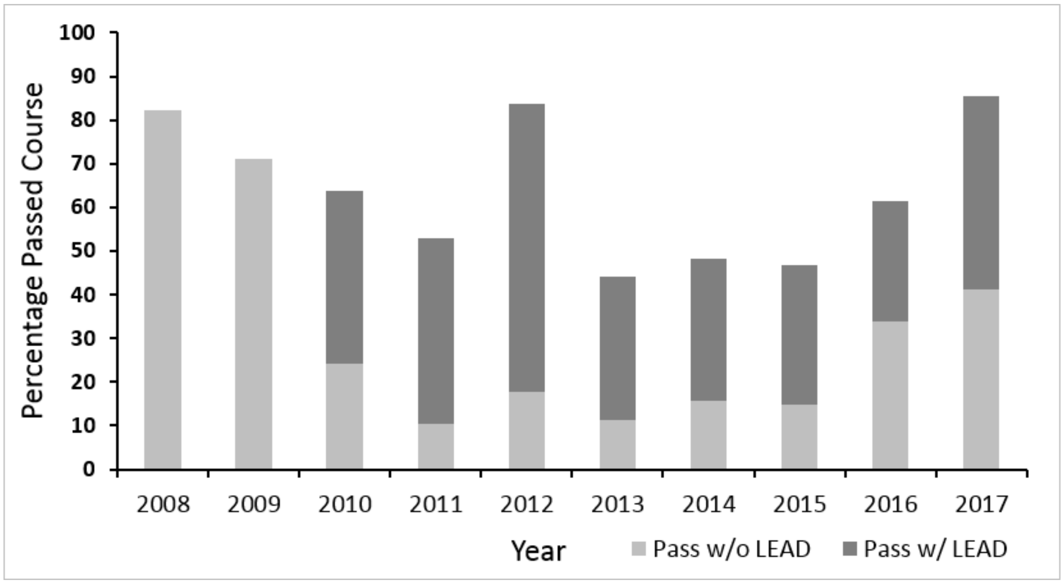


Figure 5.17. Percentage of students with a passing grade for general chemistry versus yearly spring LEAD participation

The influence of LEAD attendance on student success was more closely analyzed by comparing overall course percentage to individual number of attendances in Figure 5.19. Figure 5.19 indicates the standard deviation (gray lines) around each number of attendances starting at 14 attendances similar to the fall plot (4.3) which is equivalent to one LEAD participation per week.

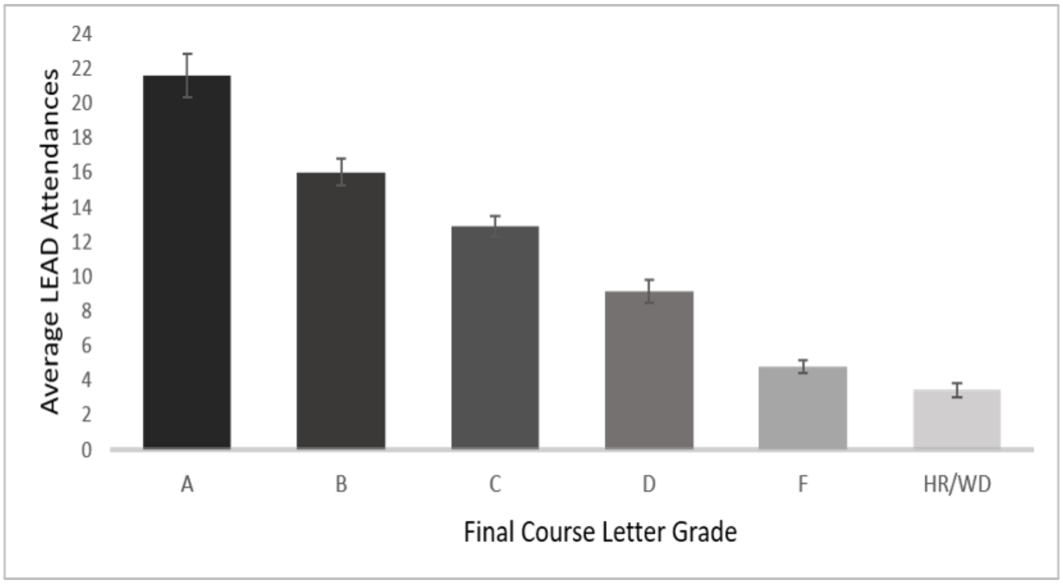


Figure 5.18. Average LEAD attendance by final spring semester CHEM 1310 letter grade

Similar to the fall semester CHEM 1310 LEAD attendance data, the average course scores as related to LEAD attendance become less reliable at higher number of attendances due to fewer students participating this often.

While the trend was similar to that observed for the fall semester data, there were some key differences. While zero attendances in the fall semester corresponded to a nearly passing score, at zero attendances for spring semester students the average score was approximately 8% lower. At the measure of one attendance per week, standard deviation of percentage score for spring semester students remains between 5 – 10% lower than the fall value while standard deviation of the percentage remained above passing. Additionally, at one attendance per week the score based on attendance no longer went below a passing score of 70% while this does not occur consistently for spring semester students until approximately two attendances per week. This would further corroborate that spring semester students are lower performing as compares to students in the fall semester of CHEM 1310. LEAD attendance related to self-selected groups of the Student-Choice model were also analyzed, this comparison is given in Figure 5.20.

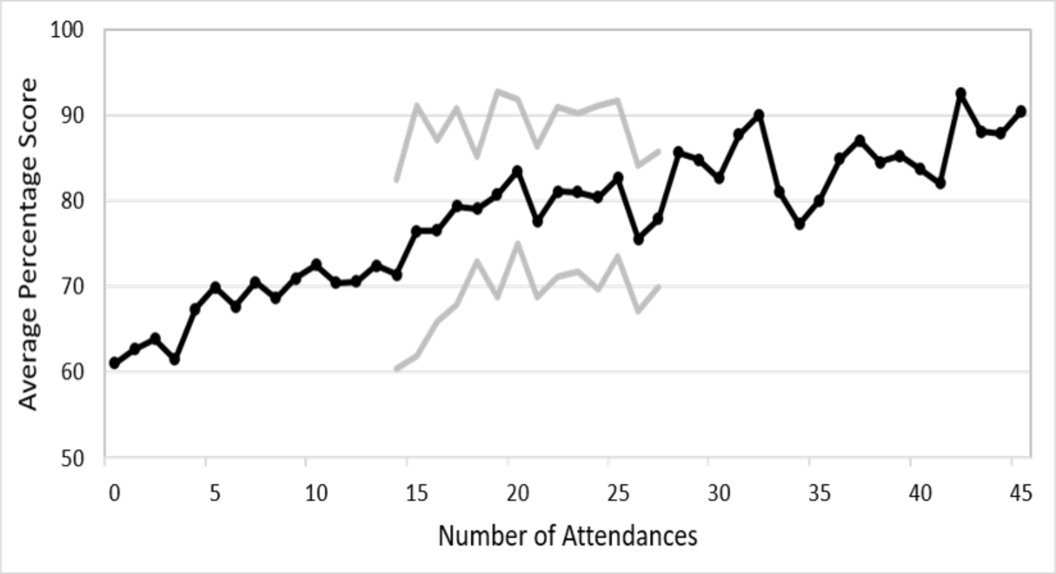


Figure 5.19. Average spring semester CHEM 1310 percentage score based on number of LEAD attendances

The comparison indicated a higher average number of LEAD attendances per each self-selected group as compared to that observed during the fall semester of CHEM 1310. The only exception to this increased attendance were students in group C (F2F lecture and online recitation) who had comparable attendance to that of students in the fall semester. A dditionally, students in group B (online lecture and F2F recitation) and D (fully online) had the highest LEAD participation during the spring semester which was opposite that observed during the fall semesters.

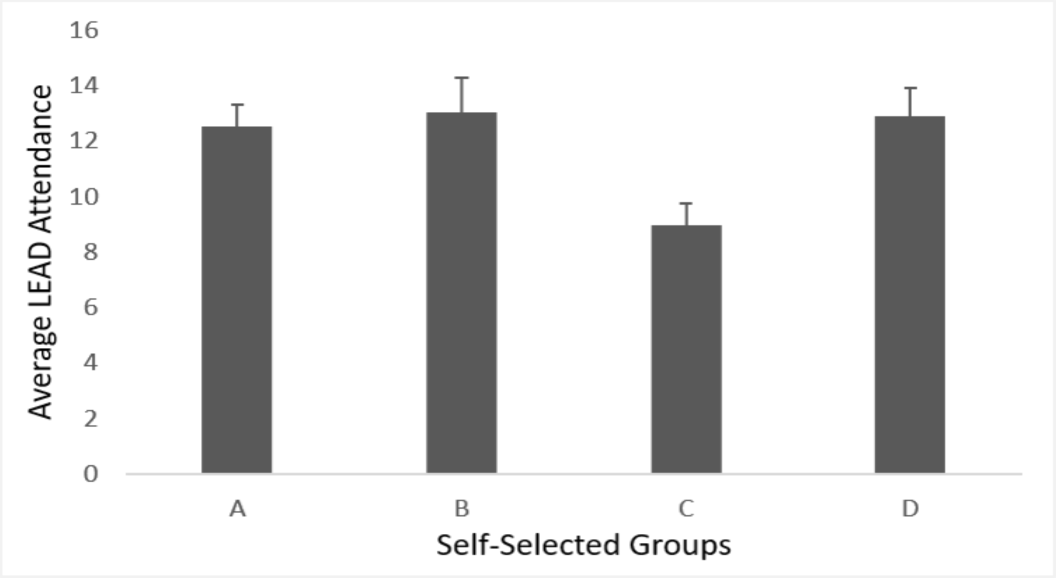


Figure 5.20. Average spring LEAD attendance based on self-selected group of the Student-Choice model

Finally, average final course percentages were compared for students in each self-selected group relative to LEAD participation and is shown in Figure 5.21.

As has been observed in all previous LEAD analyses, students attending LEAD, on average, had higher performance within the course regardless of self-selected group. As relates to the self-selected group analysis for fall (see Figure 4.5), while students who attended LEAD had higher performance, the observed difference in average course scores was lessened during the spring semesters of CHEM 1310.

5.4. SUMMARY

The spring-semester analysis served as a needed secondary study in more strongly confirming the effects of student-choice implementation in addition to allowing for further analysis of outcomes related to LEAD participation. The spring-semester offering of CHEM 1310 had inconsistencies when compared to the fall semesters, most of which were eliminated through standardization of the course with fall semester. During the initial effort to standardize the spring with the fall course offerings, addition of a second section in spring was able to accommodate increased enrollment.

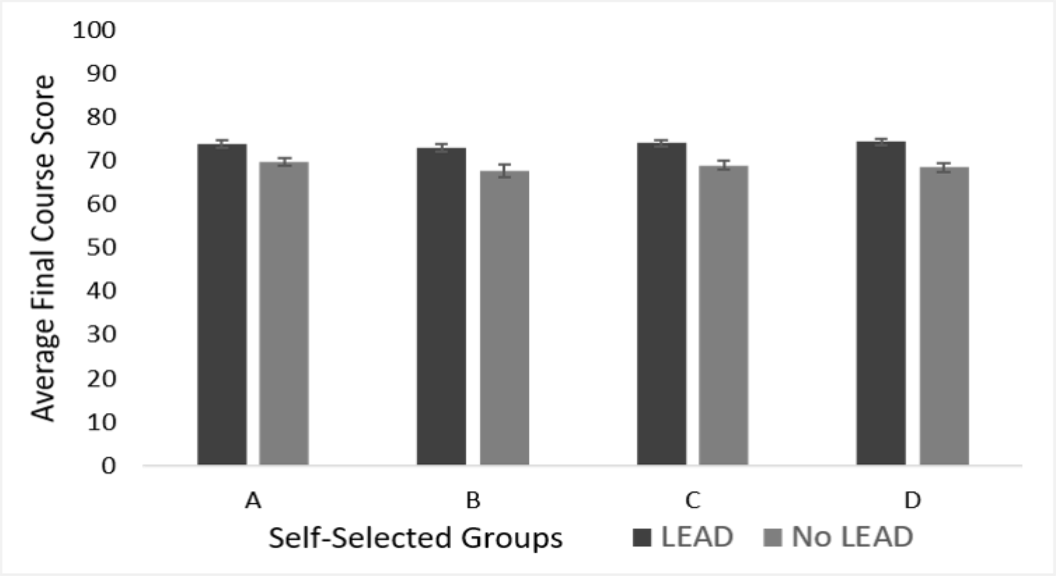


Figure 5.21. Average final course score for spring semester CHEM 1310 students in each self-selected group based on LEAD attendance

This change brought the spring semester more in line with fall standards by requiring instructor collaboration between the two lecture sections so that a similar experience was provided to both sections. By implementing the Student-Choice model, spring CHEM 1310 course standards were brought fully into alignment with the standards experienced by students during the fall.

Through course alignment, the hypothesis that spring CHEM 1310 students on average are lower performing was more directly observable. Trends to overall student grades followed a similar pattern in both fall and spring semesters, albeit with spring semester scores being generally depressed relative to the analyzed fall semesters. Additional evidence towards confirming spring semester students as being lower performing on average comes in observation of the pass rate which is found to be relatively steady during fall semesters. Student pass rates during the spring semesters consistently fluctuated prior to redesign, with typically fewer students earning a passing score.

Observations of LEAD attendance and related grade data also seem to support the hypothesis that students have lower performance during spring semester CHEM 1310.

Spring semesters students on average required an increased number of attendances relative to fall semester students to earn the same letter grade, indicative of higher need of assistance. Average grades tracked against LEAD attendance remained consistently lower than that observed in the fall suggesting a higher number of LEAD participations were necessary to reach the same goals of those found in the fall.

In spite of the lower performance observed by students in spring semesters of CHEM 1310, implementation of the Student-Choice model in conjunction with the redesign of LEAD seemed to maintain similar patterns as those observed in the fall. Grades remained more consistent in post-redesign years, similar to what was determined in the fall semesters. After the mandatory sampling rotation, students still indicated a preference for online options over F2F, though to a lower degree than that observed in the fall. Additionally, between all self-selected groups, there were no significant differences observed in overall performance. While all of the data discussed suggests the effectiveness of the Student-Choice model, continual improvement remains necessary to further improve student outcomes particularly during the spring semester offerings of CHEM 1310.

6. CONCLUSION

6.1. SUMMARY

Implementation of the Student-Choice redesigned general chemistry course at Missouri S&T was a necessary step initiated in part by a need to accommodate increasing enrollment amidst limited resources. As a result, the redesign also served as an effective foundational step for course modernization in order to more effectively meet the needs of contemporary learners with a variety of preferred learning styles. Shifting the course away from time spent in passive lectures gave students increased opportunity to engage in learning the course material through recitations which were redesigned to be more focused on active practice. Addition of online sections for lecture and recitation proved to be popular avenues for course participation. Inclusion of a mandatory sampling rotation allowed students to try the different options and subsequently make a more informed choice. While technical differences related to course delivery and student collaboration opportunities existed between online and F2F options, educational quality was not sacrificed.

Typical of many redesigns, the data indicates mixed results. Student performance within the various categories ran the gamut of possibilities from decreased, consistent, and increased, with overall course scores remaining consistent. While changes in performance varied between categories, when comparing the pre- and post-redesign semesters, performance typically appeared more stable during post-redesign semesters. Closer inspection of data comparing the four available self-selected groups indicated few identifiable differences to student performance regardless of student choice. From the information presented the redesign of CHEM 1310 via implementation of the Student-Choice model was successful at achieving the major goals which served as its initiators. Additionally, the redesign gave students more stewardship over their learning experience while also maintaining or improving the general quality of the course [71, 82].

6.2. SUGGESTED FUTURE DIRECTIONS

While the Student-Choice model implemented was a positive first step for improving the quality and capacity of CHEM 1310 at Missouri S&T, additional study should be considered. These further studies should be directed with the goals of continuing to not only improve CHEM 1310, but also finding ways to adapt positive redesign tactics to other courses when possible. A more detailed list of considerations for future study includes:

- Cohort studies involving other gatekeeper courses as well as other courses for which CHEM 1310 serves as a prerequisite in order to determine what, if any second or third order effects exist from the redesign of CHEM 1310
- Deeper analysis of outlier and lower performing students to determine common issues in order to develop strategies to improve student outcomes
- Further analysis of spring semester deficiencies in order to determine causes for lower performance relative to that of fall semester students
- Viability of integration of additional course participation options such as asynchronous lecture into the CHEM 1310 framework
- Methods to improve and tailor the CHEM 1310 course experience as it relates to instruction and assessment for both major and non-major students
- Methods to improve ULA selection and training with a focus on communication skills and problem-solving ability and less reliance on previous grade in course

6.3. CONTRIBUTIONS

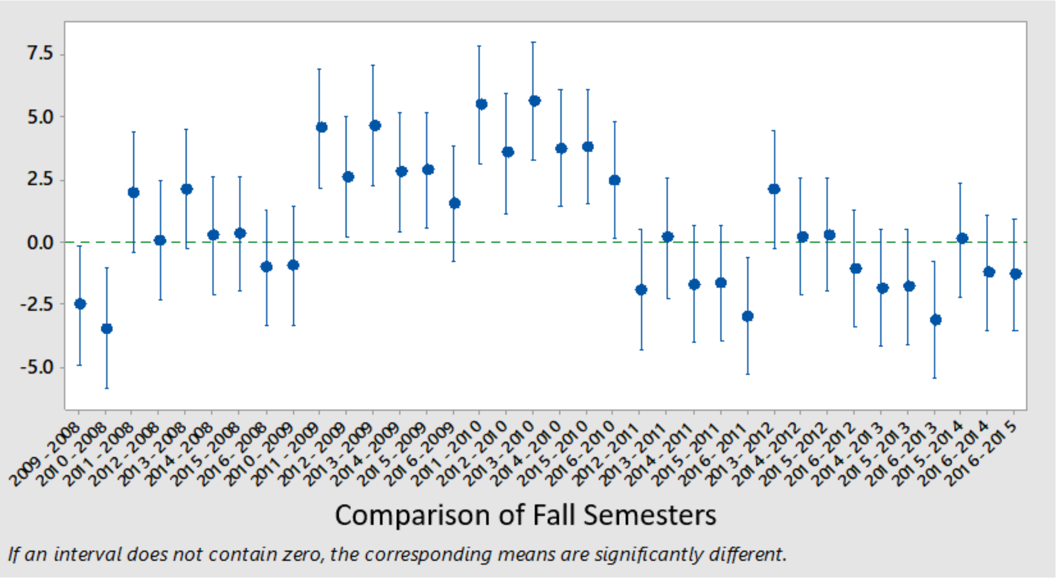
The redesign of CHEM 1310 was essential at providing a needed platform for the initiation of more widespread changes, not only within the chemistry department, but within the wider university community. Changes to CHEM 1310, led to the redesign of the accompanying general chemistry lab (CHEM 1319). Redesign of CHEM 1319 was accomplished by modernizing the lab experience through incorporation of labs in the commons along with traditional lab experiences. As an additional benefit to the general chemistry lab redesign, the lab was able to become a true companion course to general chemistry I through course synchronization where topics introduced in one would be reinforced in the other. Another chemistry course influenced by the CHEM 1310 redesign was the follow-up general chemistry II course (CHEM 1320) which was redesigned by inclusion of an active, collaborative recitation component. The current and ongoing redesign of these cohort courses relied on and were made more effective through knowledge gained directly from implementation and study of redesign process of CHEM 1310.

External to the chemistry department, efforts involved in modernizing CHEM 1310 served as motivation and guidance towards modernizing other similar courses, including calculus I (MATH 1214) and engineering physics I (PHYS 1135), which also serve first and second year students primarily. Engineering physics I underwent a redesign subsequent to the redesign of CHEM 1310 with similar goals of accommodating increasing enrollment with limited resources while not sacrificing course quality. The physics redesign led to the creation of asynchronous online lecture sections requiring students to be self-motivated.

Results of the efforts to redesign the general chemistry course have been, and continue to be shared to the University of Missouri system and beyond. The results of the general chemistry redesign at Missouri S&T offer valuable insight into the course redesign process, but also the specific implementation of the effectiveness of a student-choice model within the context of a course serving primarily non-major students. This study has additional importance due to the information gained being directly related to its focus on a large lecture (gatekeeper) course serving a primarily first-year student or freshman demographic at a STEM-focused university. These insights have been, and will continue to be shared through publications relating the ongoing effects of this redesign and further adaptations necessitated to the ever-changing student culture.

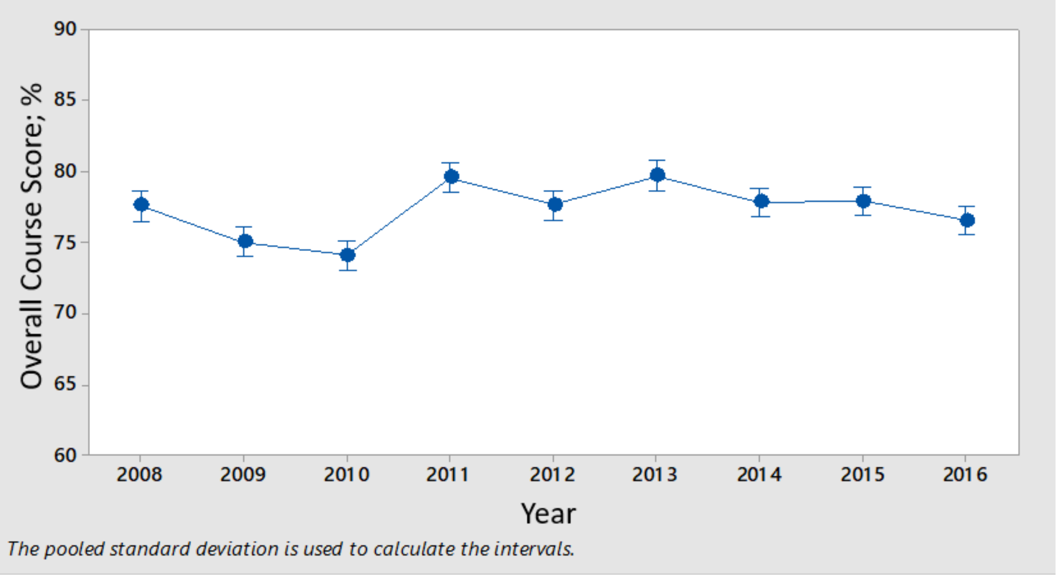
APPENDIX A

FALL SEMESTER PERFORMANCE DATA, 2008 – 2016



If an interval does not contain zero, the corresponding means are significantly different.

Tukey interval plot for overall course percentages from 2008 – 2016; ANOVA output: F(8, 6762) = 11.80, p < 0.000; $\eta^2 = 0.003$

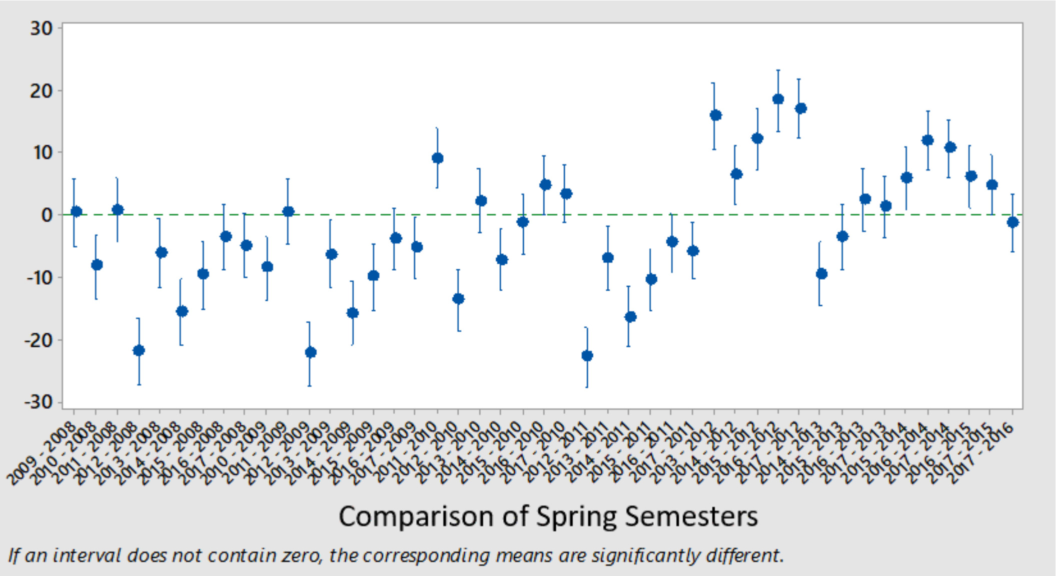


The pooled standard deviation is used to calculate the intervals.

Mean overall fall semester percentage scores, 2008 – 2016

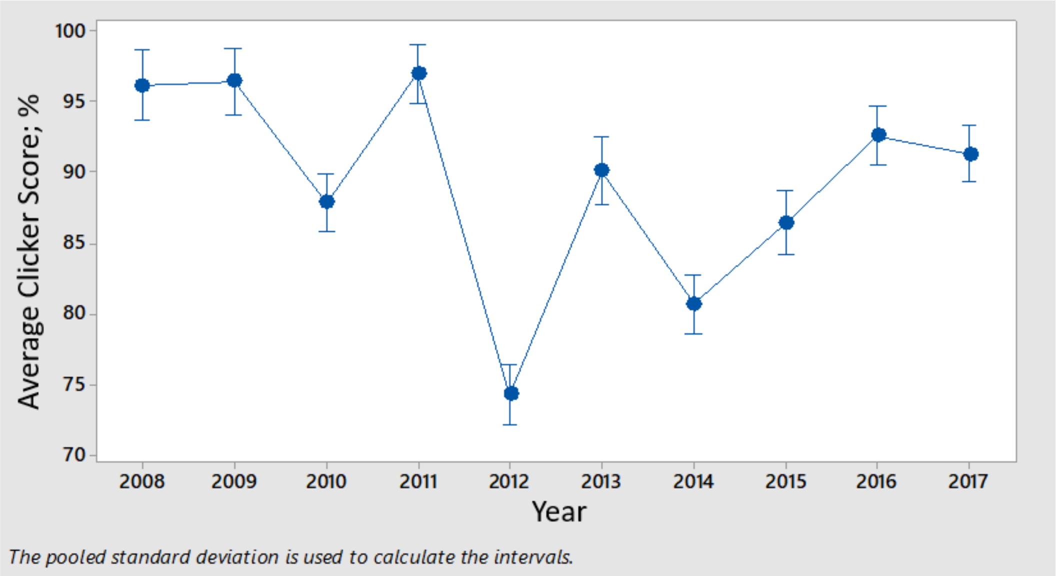
APPENDIX B

SPRING SEMESTER PERFORMANCE DATA, 2008 - 2017



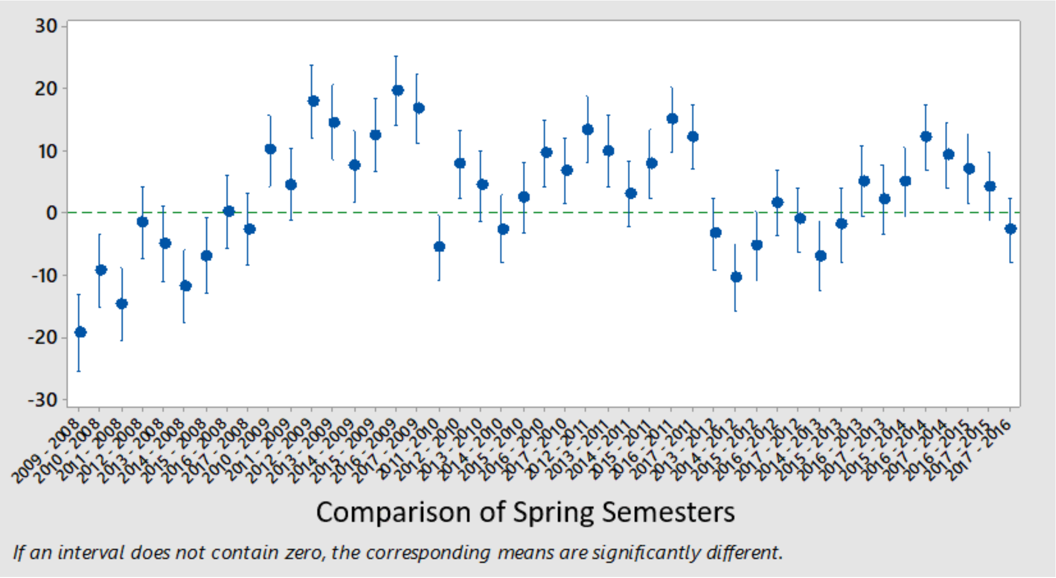
If an interval does not contain zero, the corresponding means are significantly different.

Tukey interval plot for average clicker scores from 2008 – 2017;
ANOVA output: $F(9, 2091) = 43.21$, $p < 0.001$; $\eta^2 = 0.03$

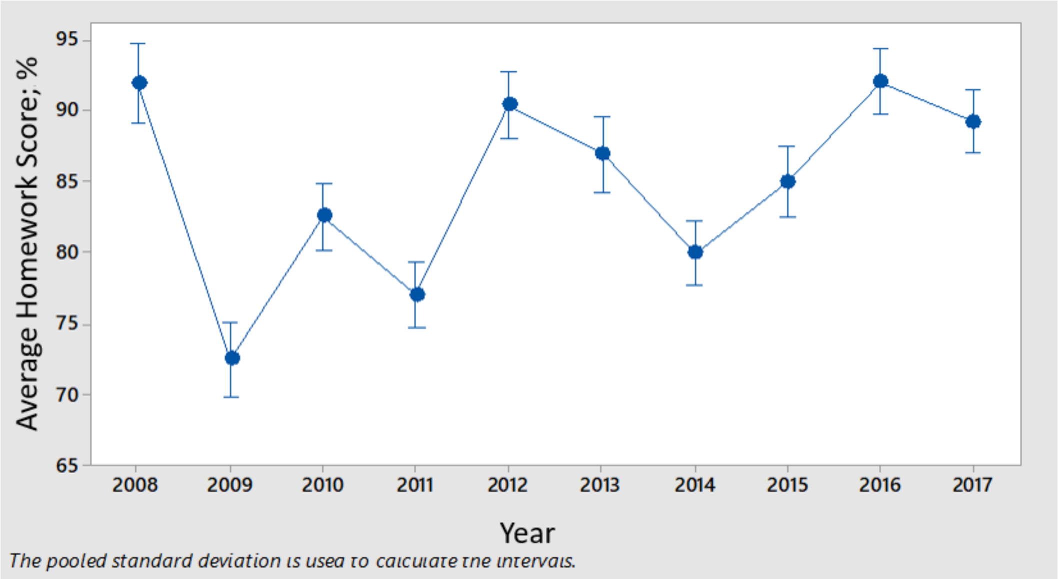


The pooled standard deviation is used to calculate the intervals.

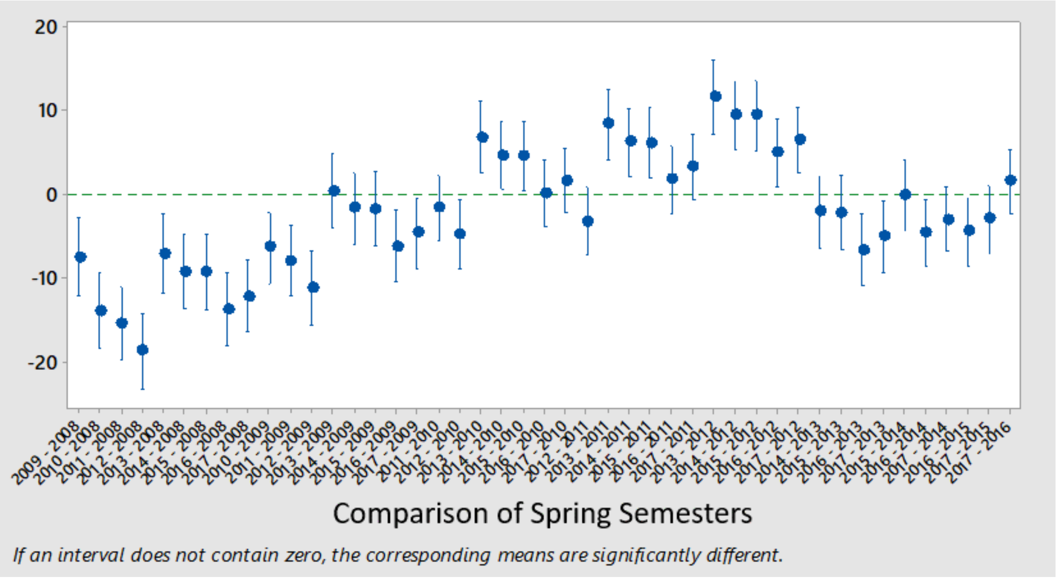
Mean spring semester clicker scores, 2008 – 2017



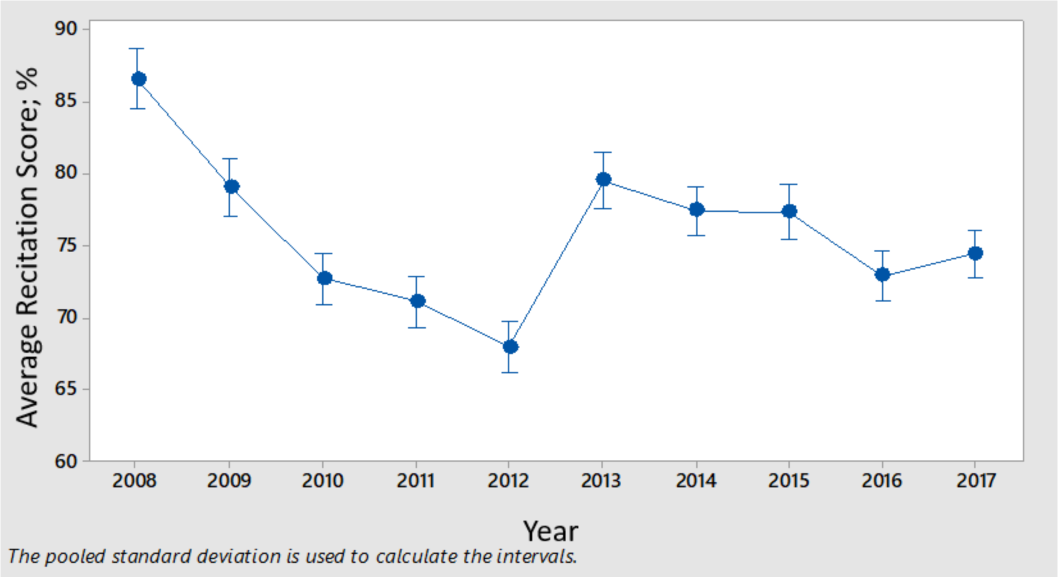
Tukey interval plot for average homework scores from 2008 – 2017; ANOVA output: F(9, 2091) = 27.50, $p < 0.001$; $\eta^2 = 0.025$



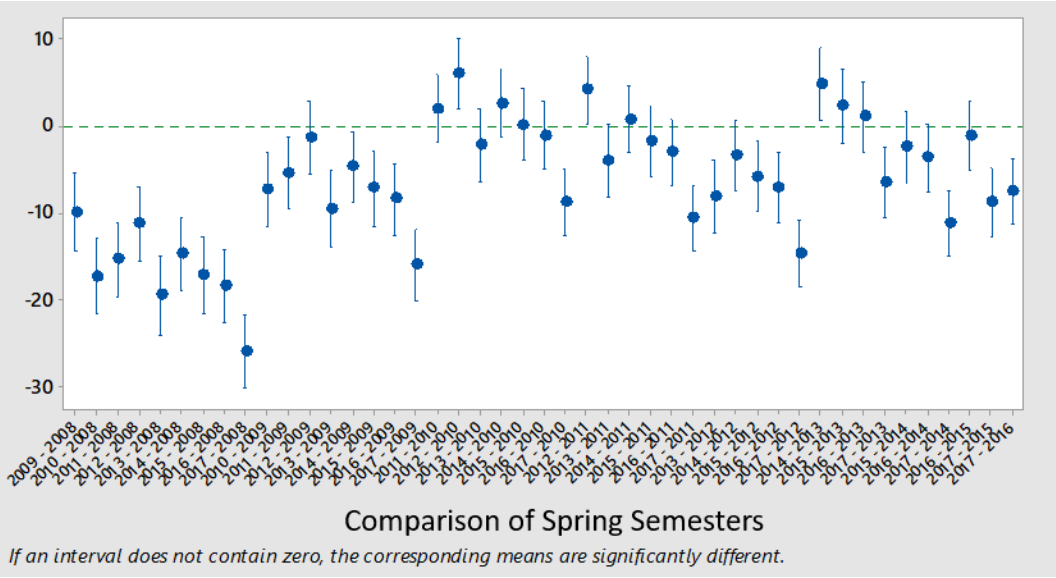
Average spring semester homework scores, 2008 – 2017



Tukey interval plot for average recitation scores from 2008 – 2017; ANOVA output: $F(9, 2091) = 28.23$, $p < 0.001$; $\eta^2 = 0.0002$

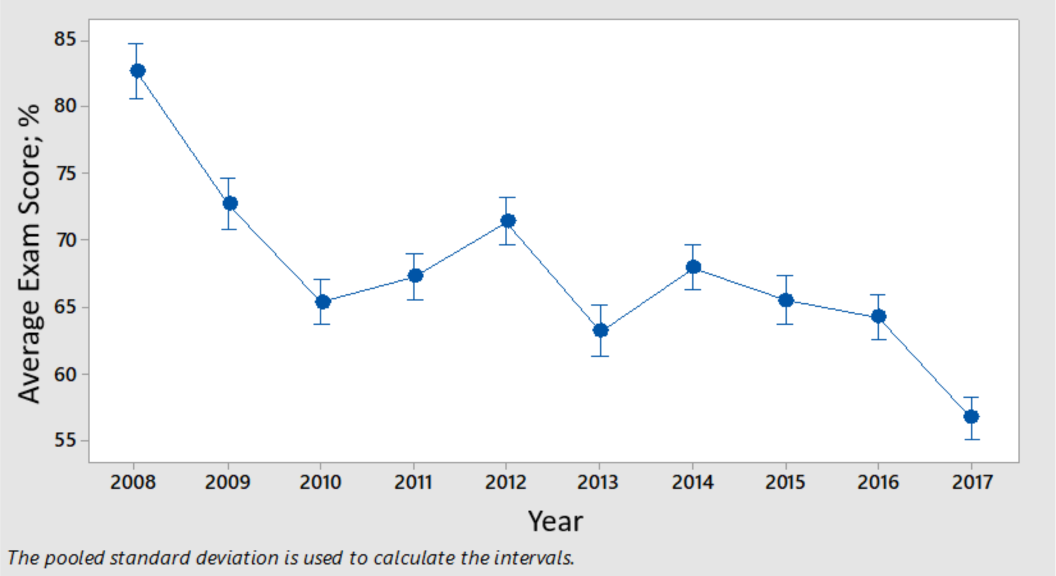


Average spring semester recitation scores, 2008 – 2017



If an interval does not contain zero, the corresponding means are significantly different.

Tukey interval plot for average exam scores from 2008 – 2017; ANOVA output: $F(9, 2091) = 52.96$, $p < 0.001$; $\eta^2 = 0.068$



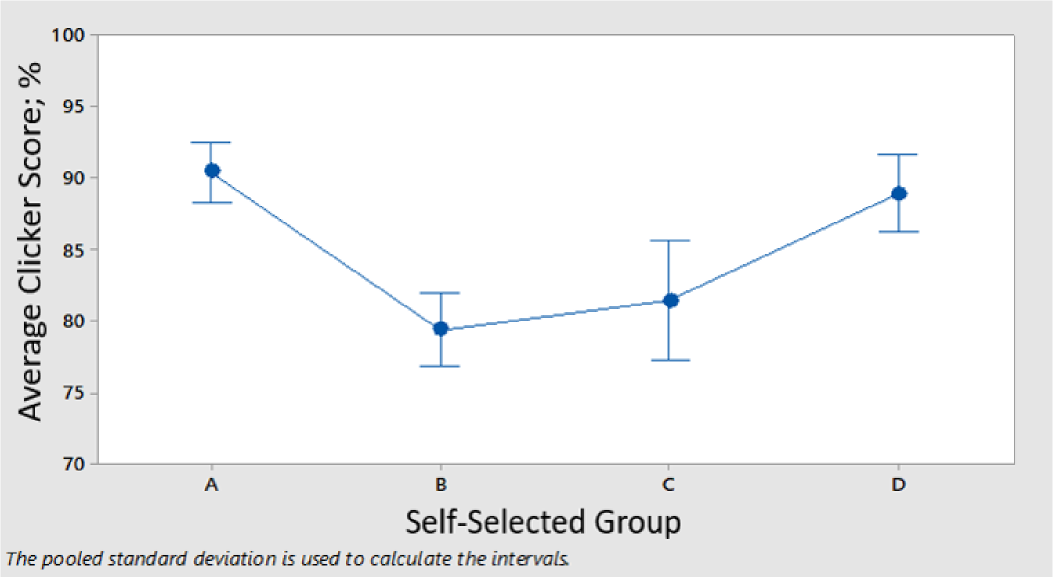
The pooled standard deviation is used to calculate the intervals.

Average spring semester average exam scores, 2008 – 2017

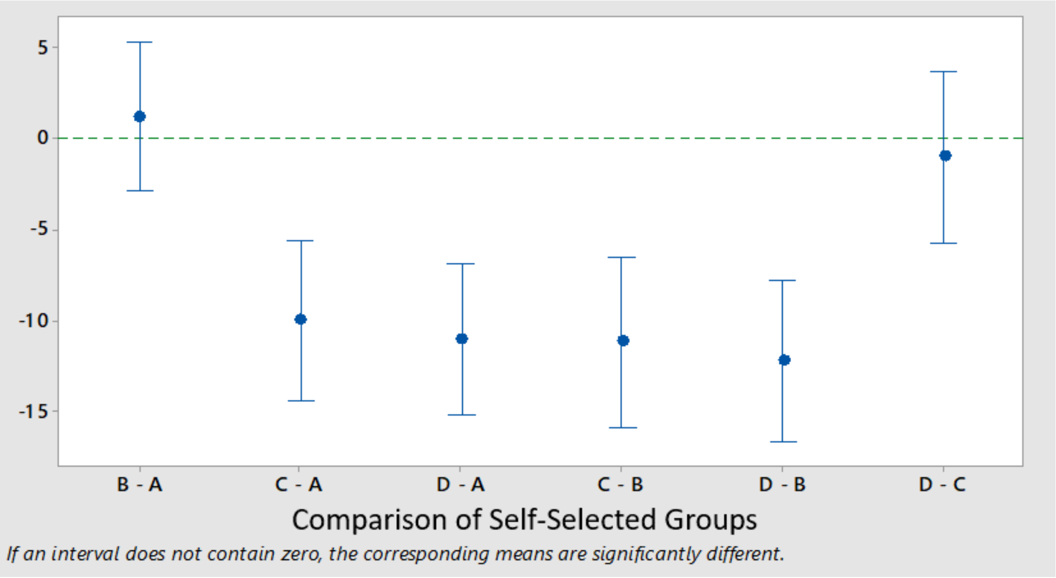
APPENDIX C

FALL SEMESTER CLICKER PERFORMANCE DATA, 2012 – 2016

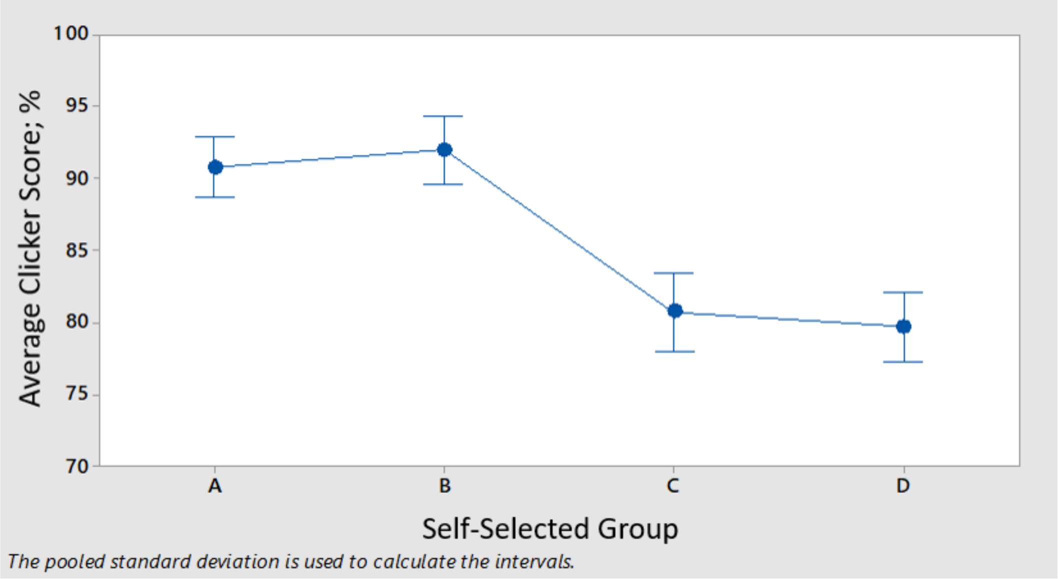
Tukey interval plot of clicker scores for self-selected groups, 2012; ANOVA output: F(3, 712) = 17.75, p < 0.001



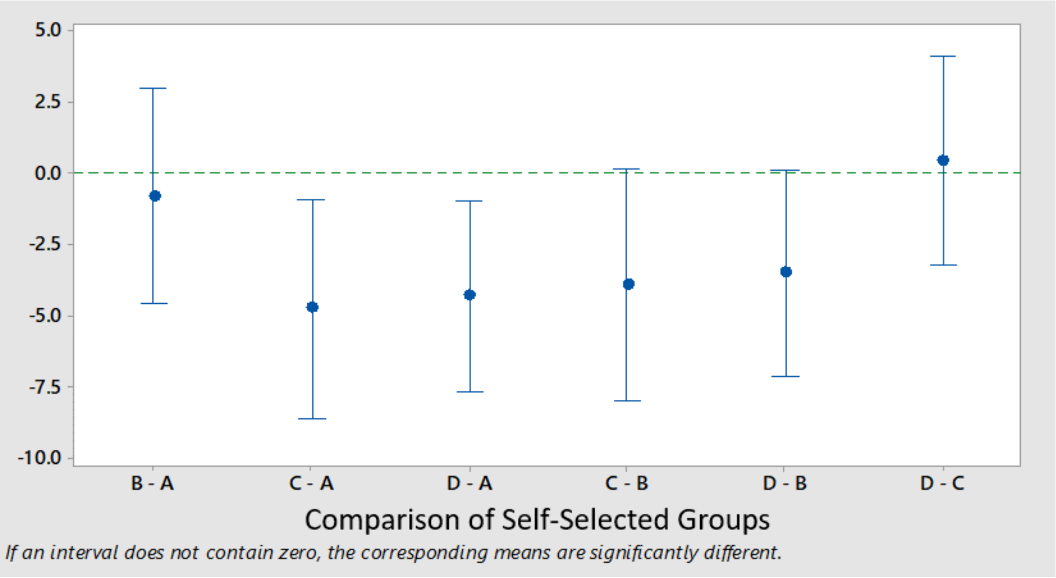
Average fall semester clicker scores by self-selected group, 2012



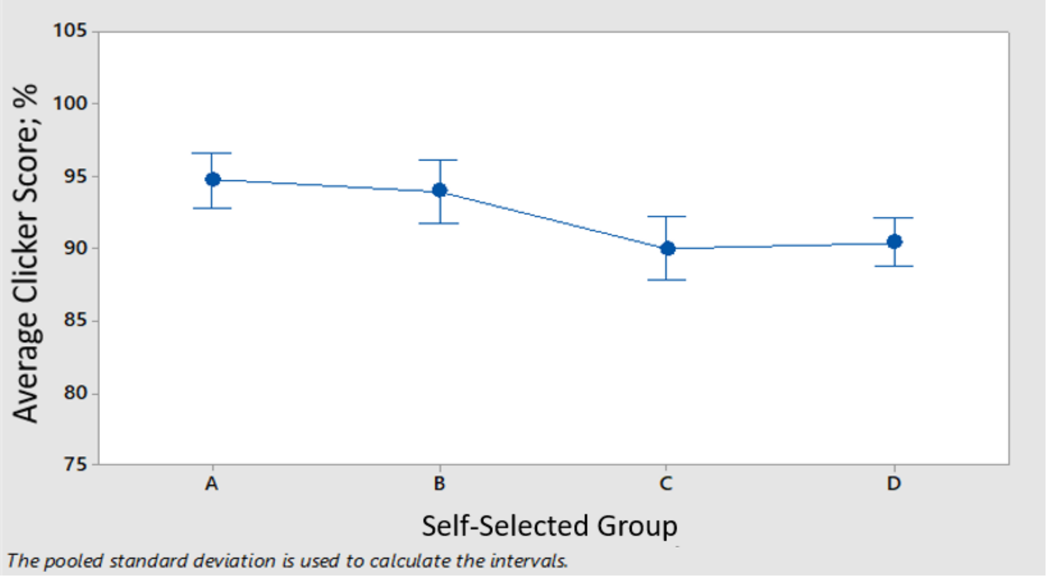
Tukey interval plot of clicker scores for self-selected groups, 2013; ANOVA output: $F(3, 718) = 28.48$, $p < 0.001$



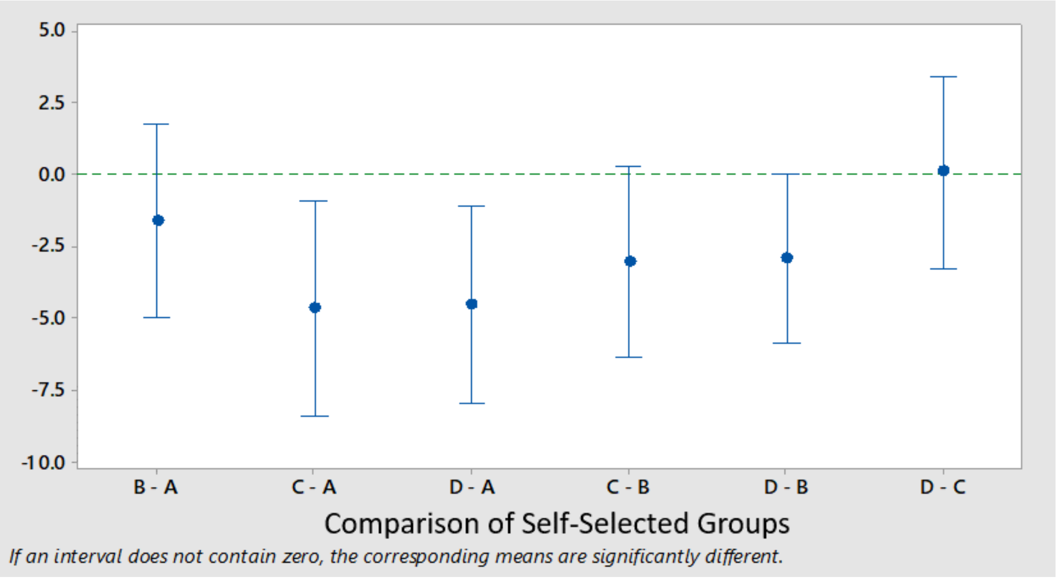
Average fall semester clicker scores by self-selected group, 2013



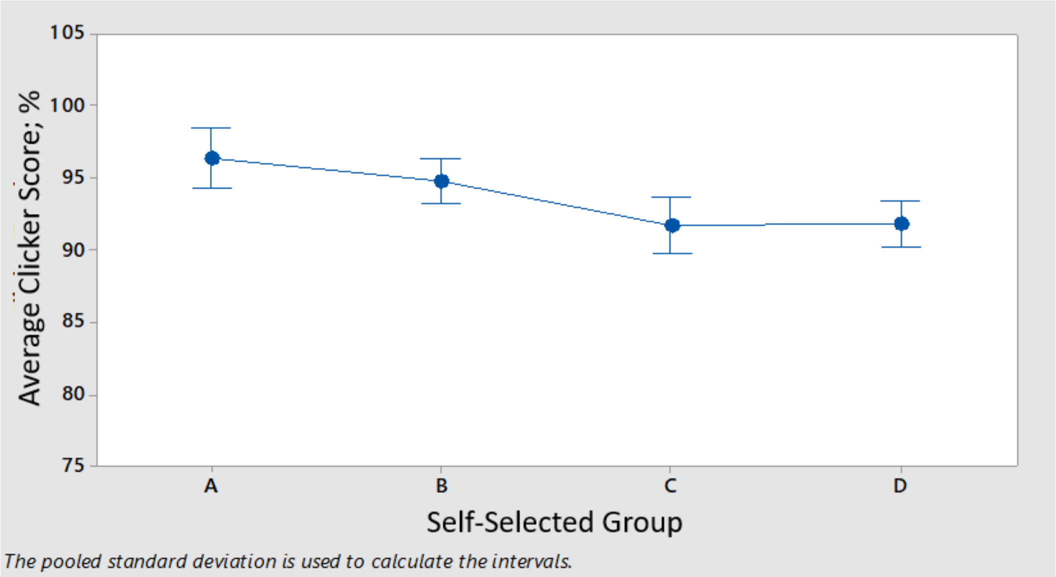
Tukey interval plot of clicker scores for self-selected groups, 2014; ANOVA output: F(3, 769) = 5.75, p < 0.002



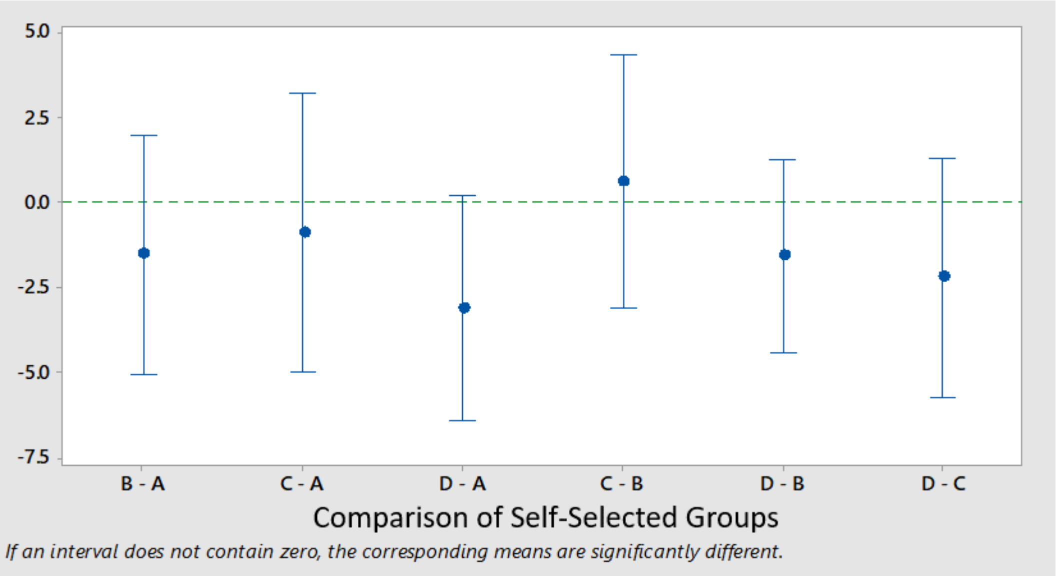
Average fall semester clicker scores by self-selected group, 2014



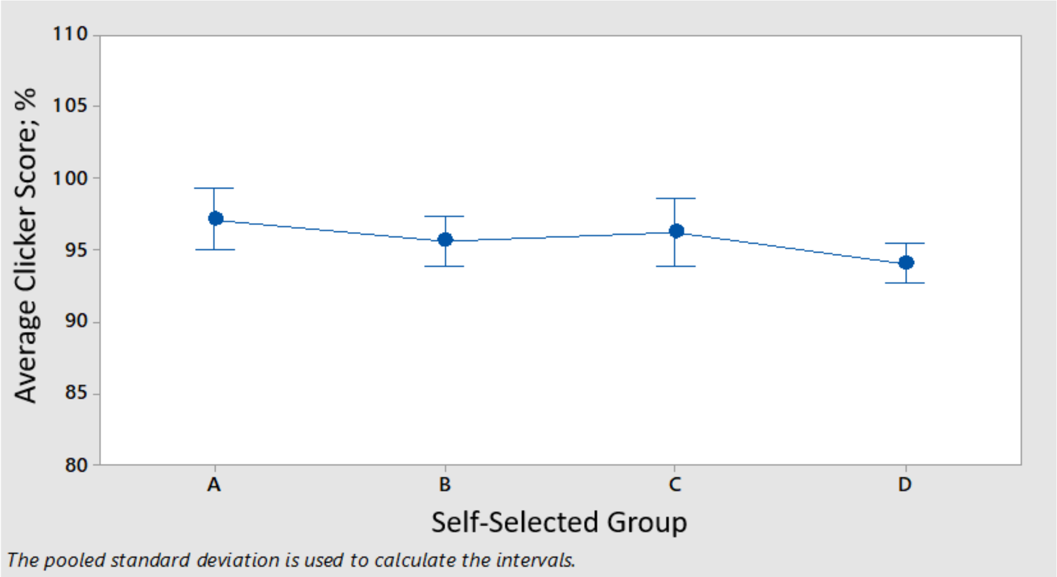
Tukey interval plot of clicker scores for self-selected groups, 2015; ANOVA output: $F(3, 851) = 5.61, p < 0.002$



Average fall semester clicker scores by self-selected group, 2015



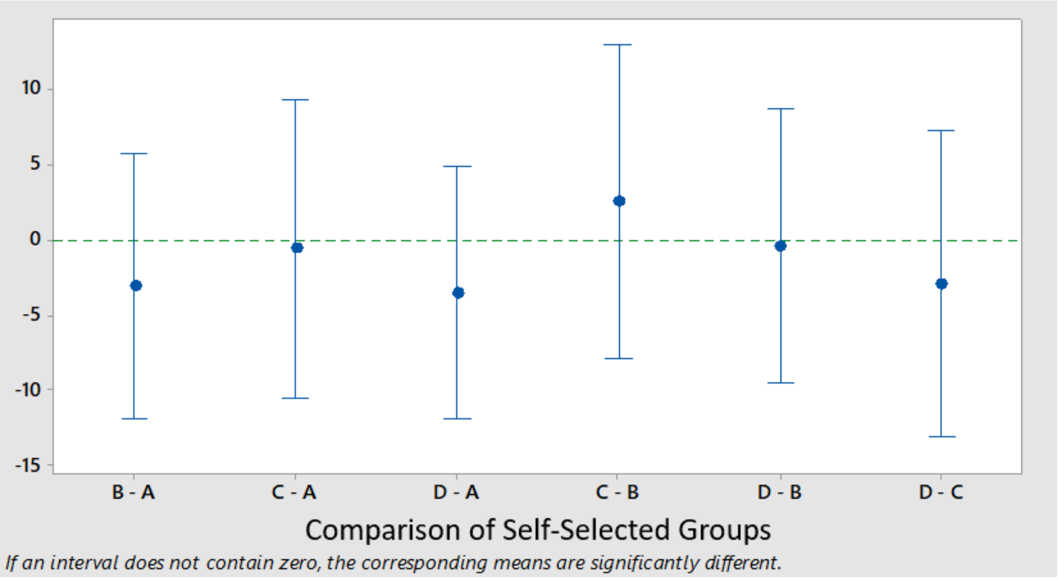
Tukey interval plot of clicker scores for self-selected groups, 2016; ANOVA output: $F(3, 805) = 2.27$, $p < 0.080$



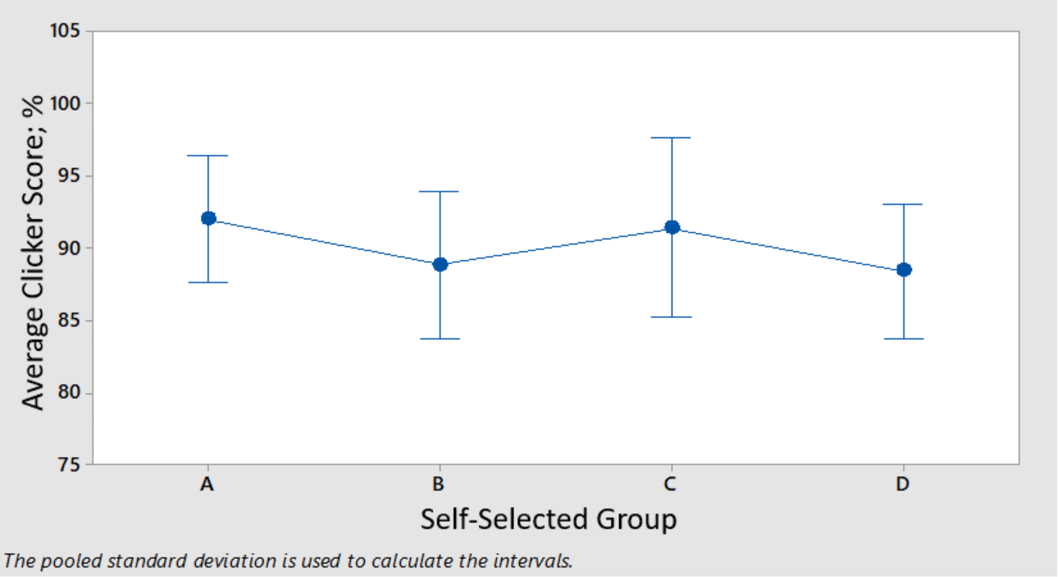
Average fall semester clicker scores by self-selected group, 2016

APPENDIX D

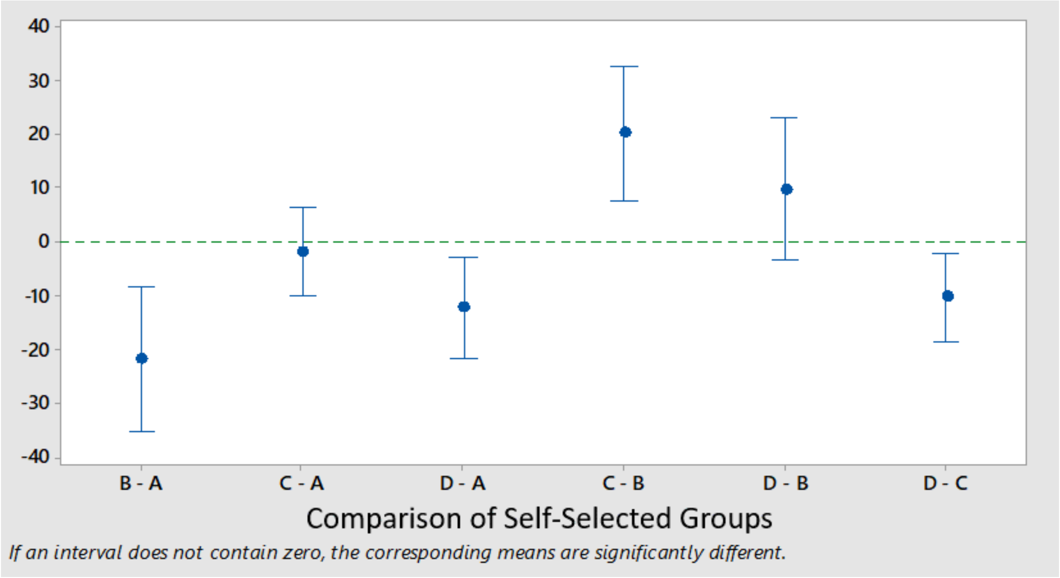
SPRING SEMESTER CLICKER PERFORMANCE DATA, 2013 - 2017



Tukey interval plot of clicker scores for self-selected groups, 2013; ANOVA output: $F(3, 175) = 0.54$, $p < 0.655$

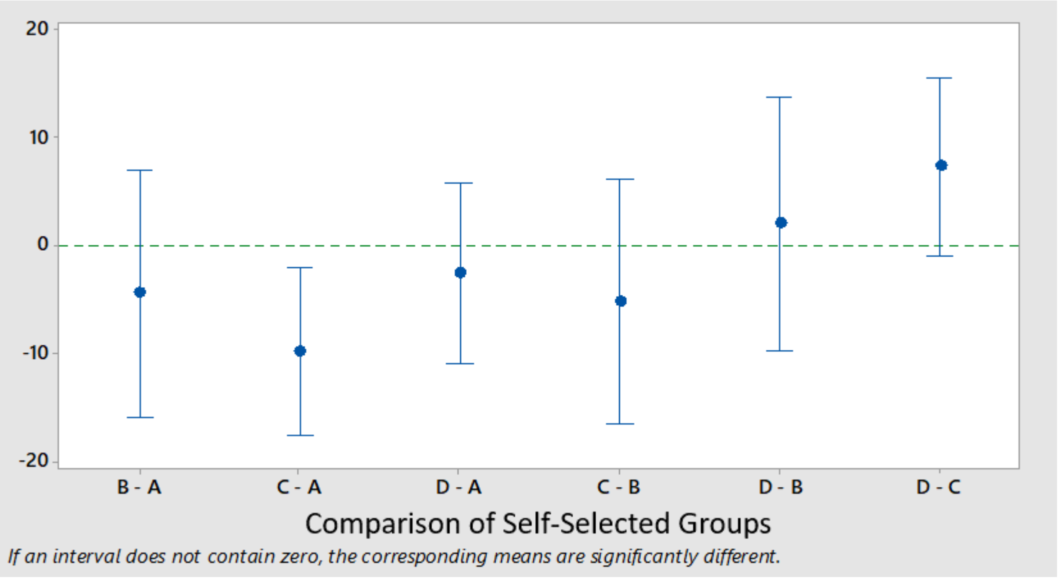


Average spring semester clicker scores by self-selected group, 2013

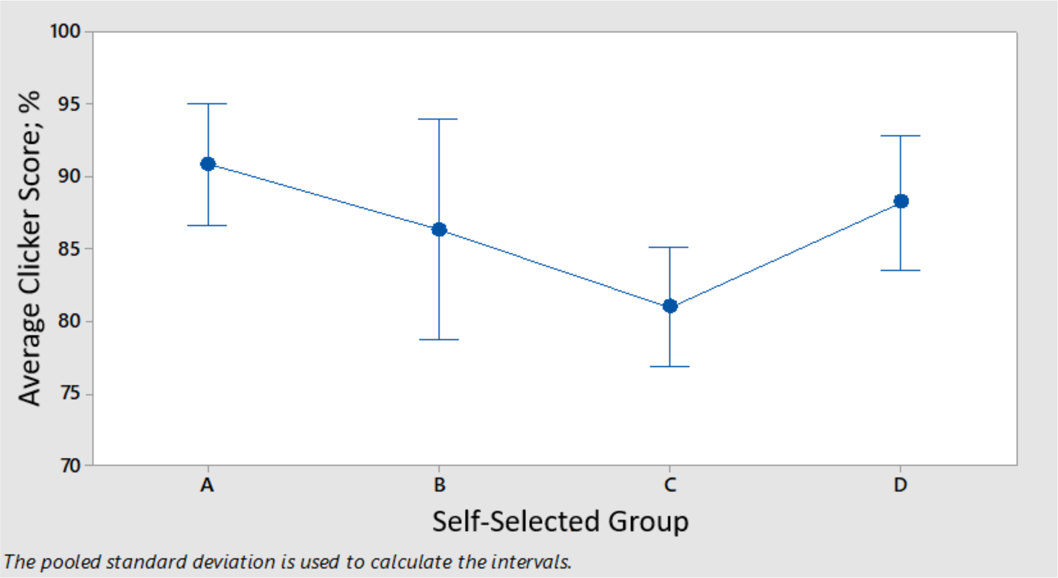


Tukey interval plot of clicker scores for self-selected groups, 2014; ANOVA output: F(3, 227) = 9.63, $p < 0.001$

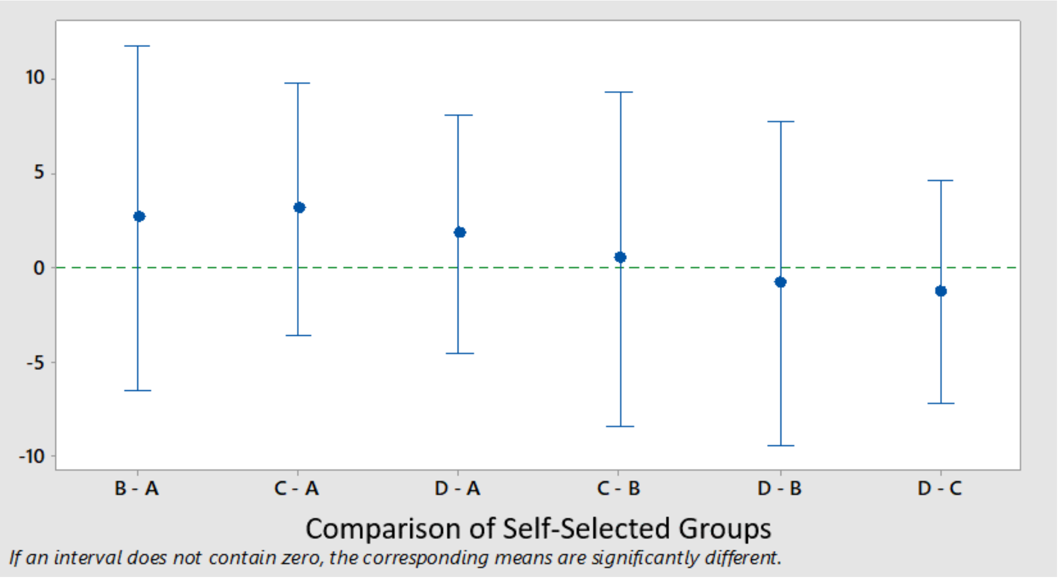
Average spring semester clicker scores by self-selected group, 2014



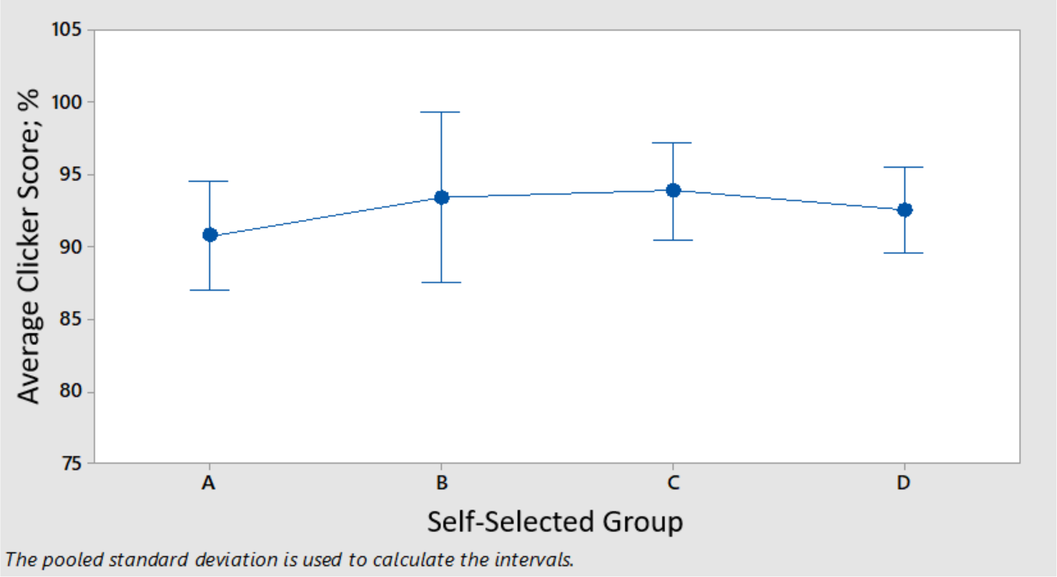
Tukey interval plot of clicker scores for self-selected groups, 2015; ANOVA output: $F(3, 193) = 3.83$, $p < 0.012$



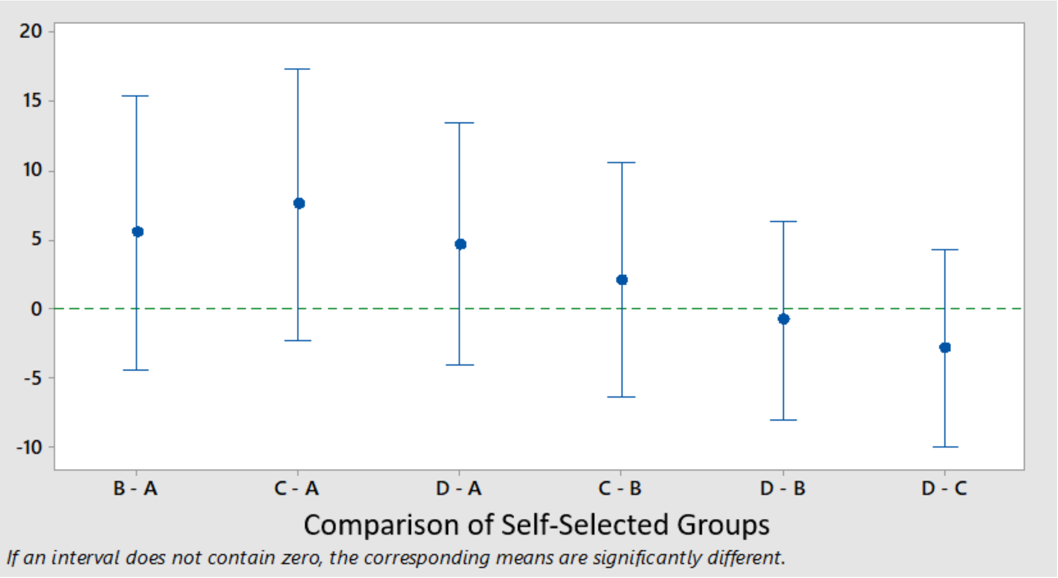
Average spring semester clicker scores by self-selected group, 2015



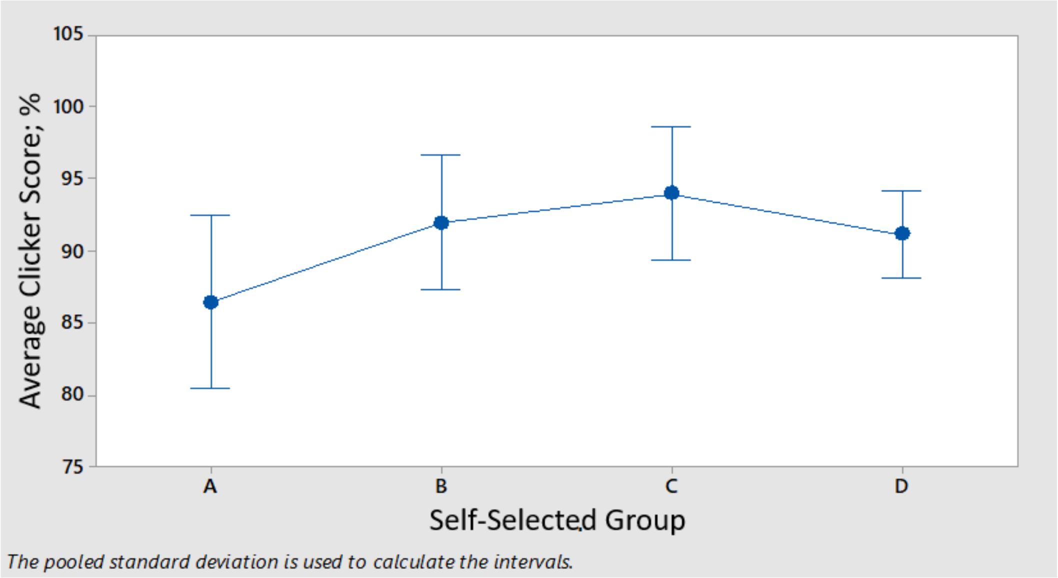
Tukey interval plot of clicker scores for self-selected groups, 2016; ANOVA output: F(3, 235) = 0.51, p < 0.678



Average spring semester clicker scores by self-selected group, 2016



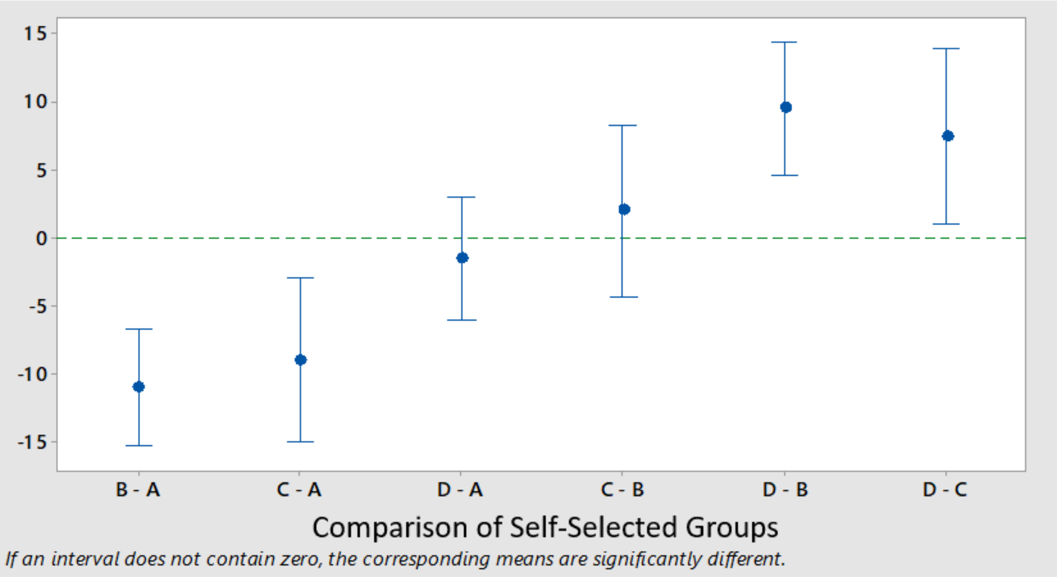
Tukey interval plot of clicker scores for self-selected groups, 2017; ANOVA output: $F(3, 251) = 1.31$, $p < 0.272$



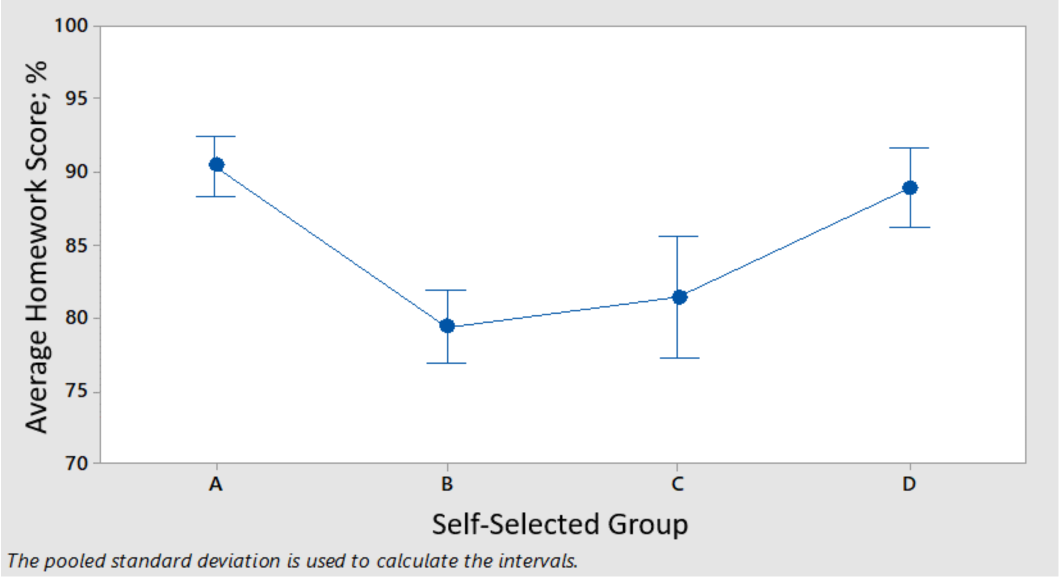
Average spring semester clicker scores by self-selected group, 2017

APPENDIX E

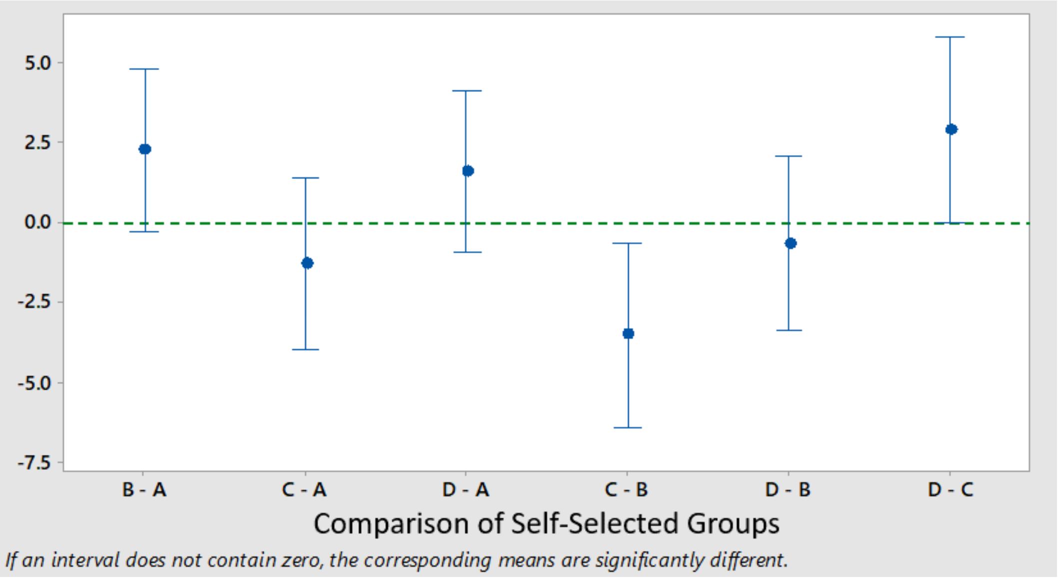
FALL SEMESTER HOMEWORK PERFORMANCE DATA, 2012 - 2016



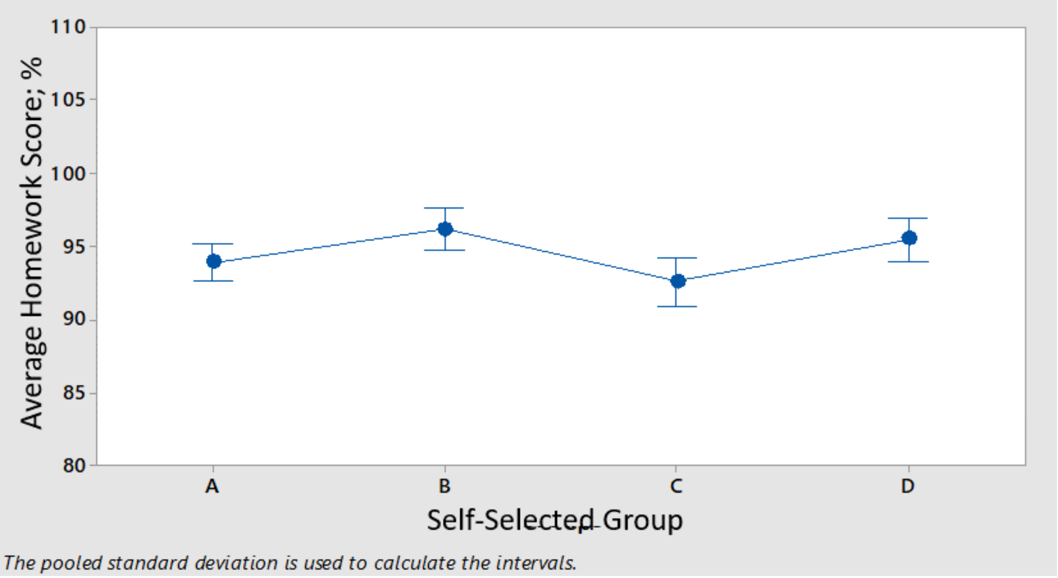
Tukey interval plot of homework scores for self-selected groups, 2012; ANOVA output: $F(3, 712) = 2.44$, $p < 0.065$



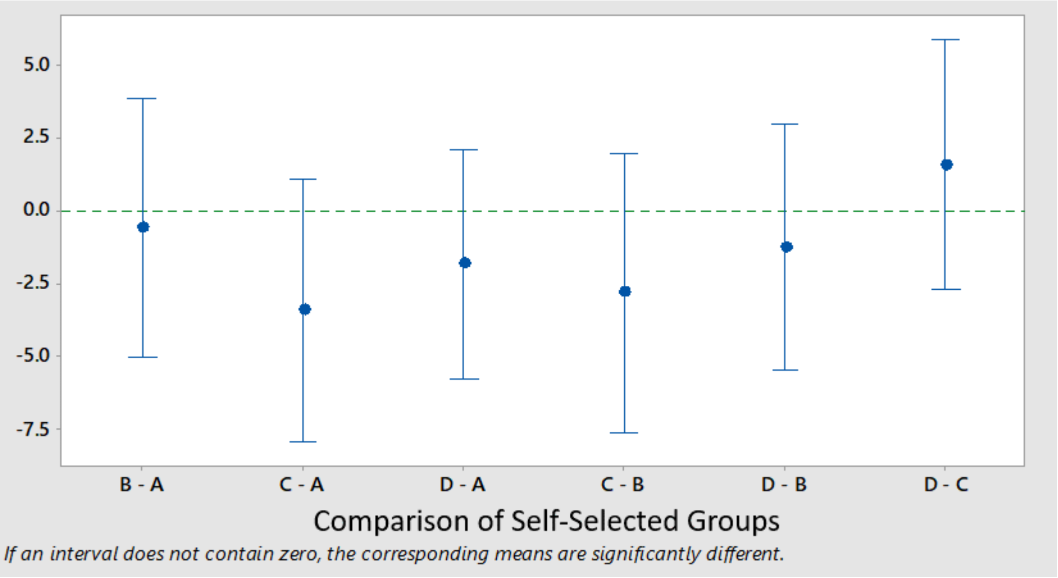
Average fall semester homework scores by self-selected group, 2012



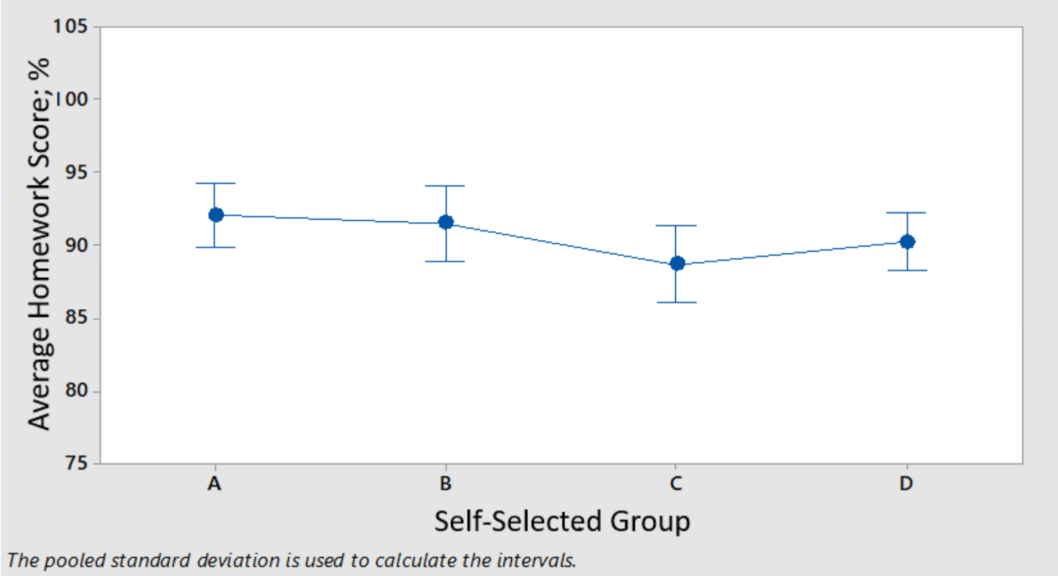
Tukey interval plot of homework scores for self-selected groups, 2013; ANOVA output: F(3, 718) = 4.14, $p < 0.007$



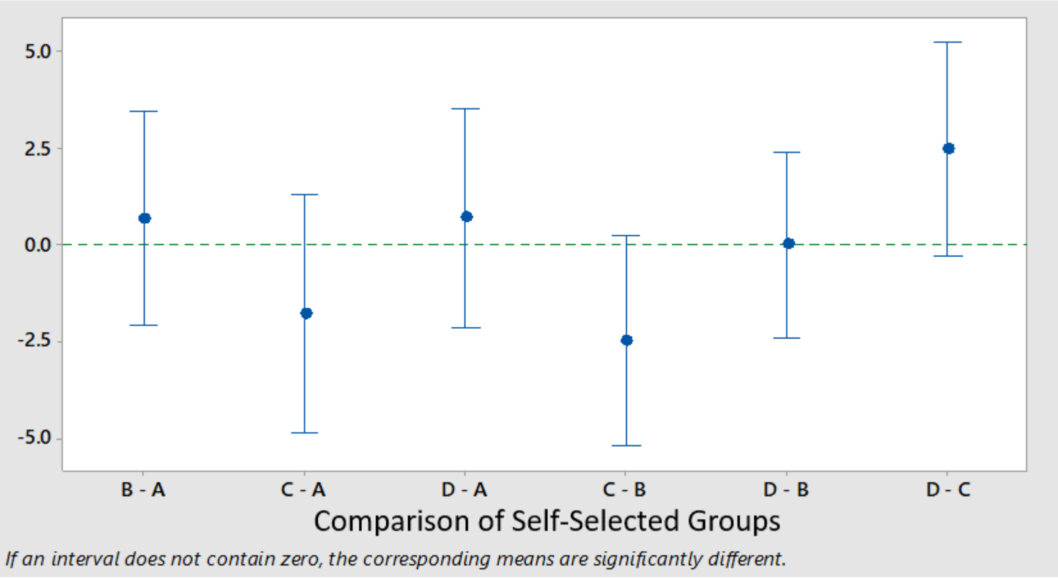
Average fall semester homework scores by self-selected group, 2013



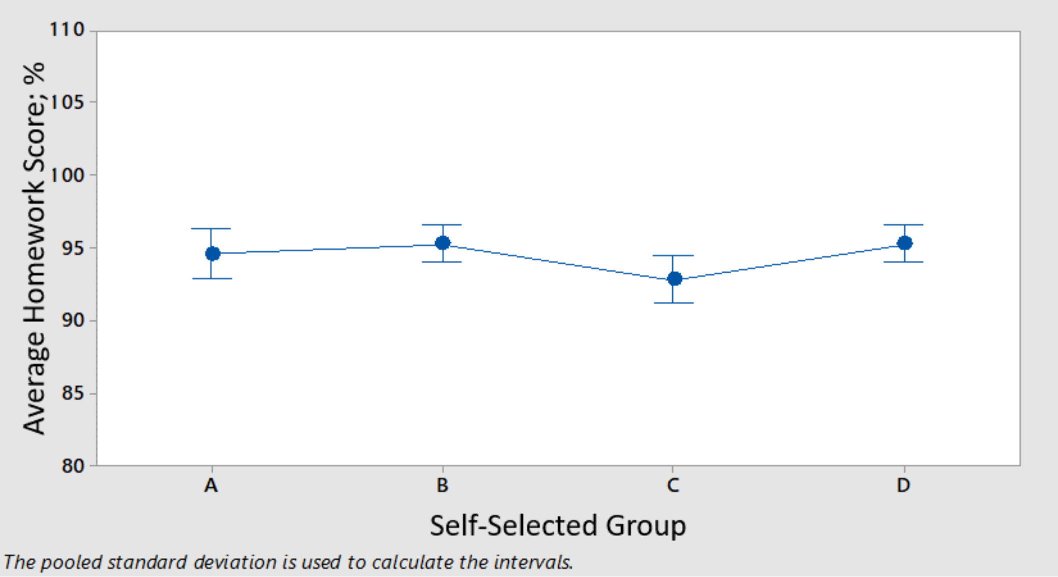
Tukey interval plot of homework scores for self-selected groups, 2014; ANOVA output: F(3, 769) = 1.45, $p < 0.228$



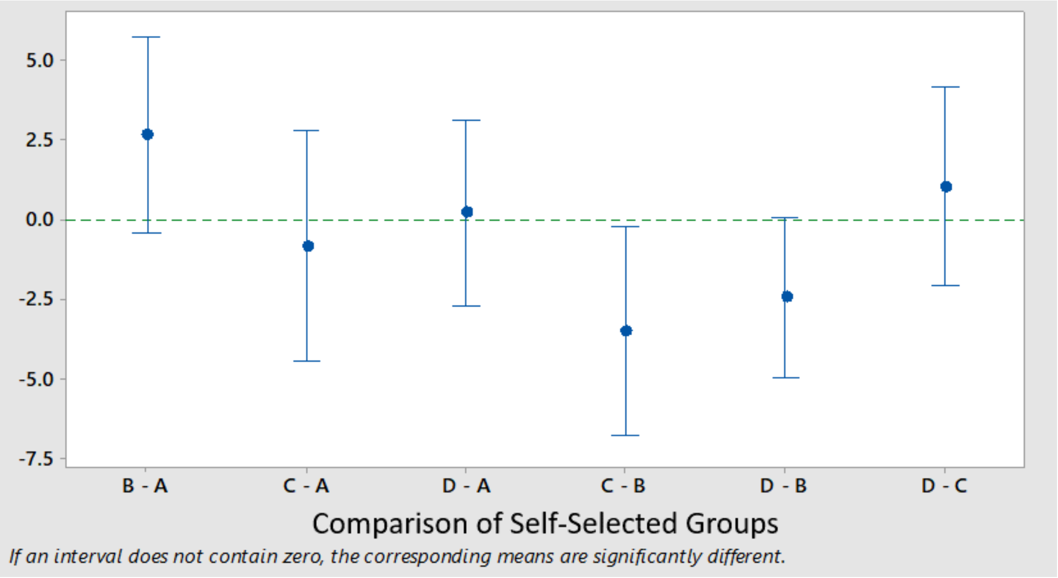
Average fall semester homework scores by self-selected group, 2014



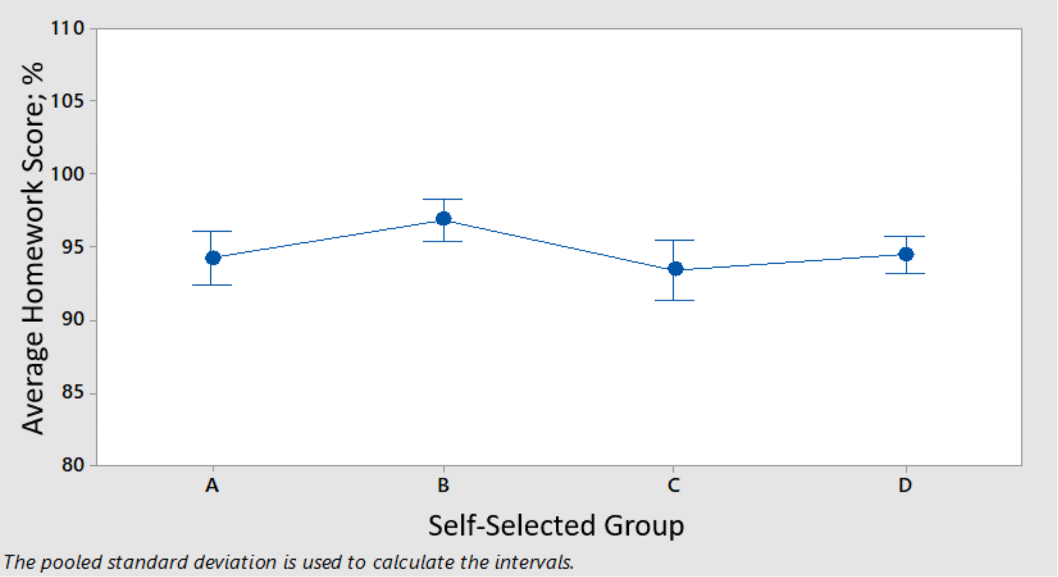
Tukey interval plot of homework scores for self-selected groups, 2015; ANOVA output: F(3, 851) = 2.25, $p < 0.019$



Average fall semester homework scores by self-selected group, 2015



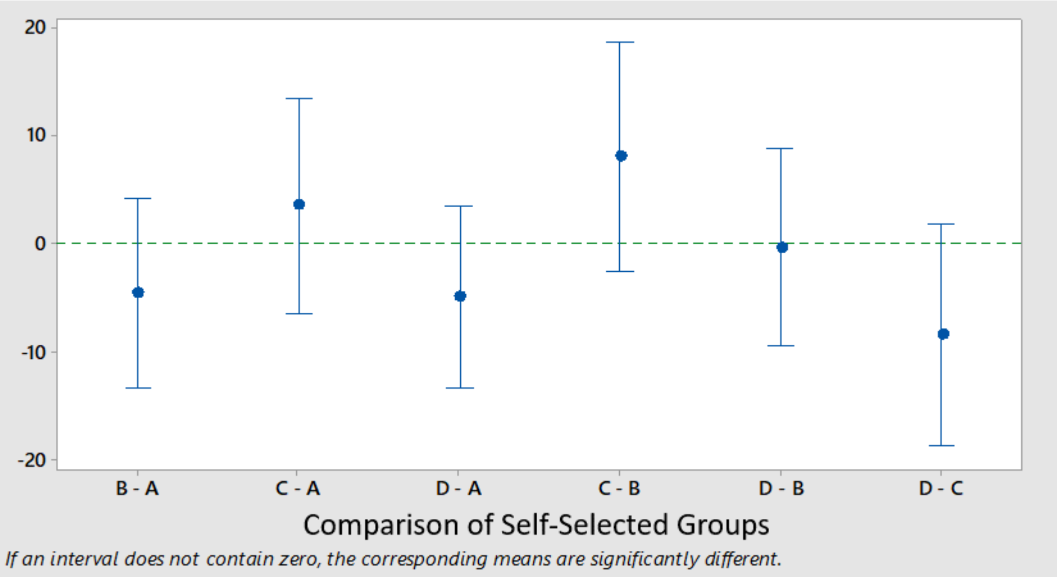
Tukey interval plot of homework scores for self-selected groups, 2016; ANOVA output: F(3, 805) = 3.37, $p < 0.019$



Average fall semester homework scores by self-selected group, 2016

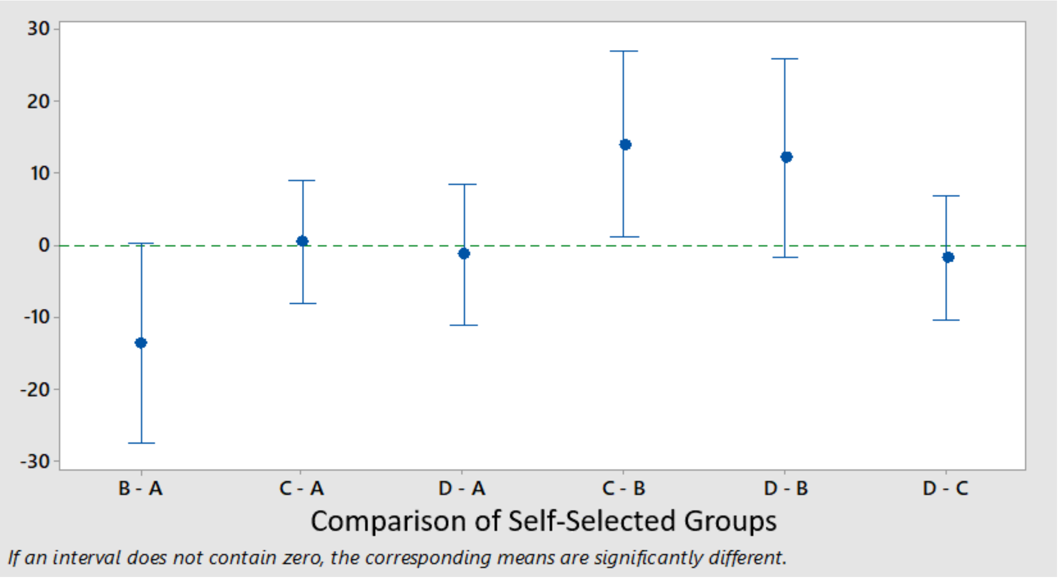
APPENDIX F

SPRING SEMESTER HOMEWORK PERFORMANCE DATA, 2013 – 2017

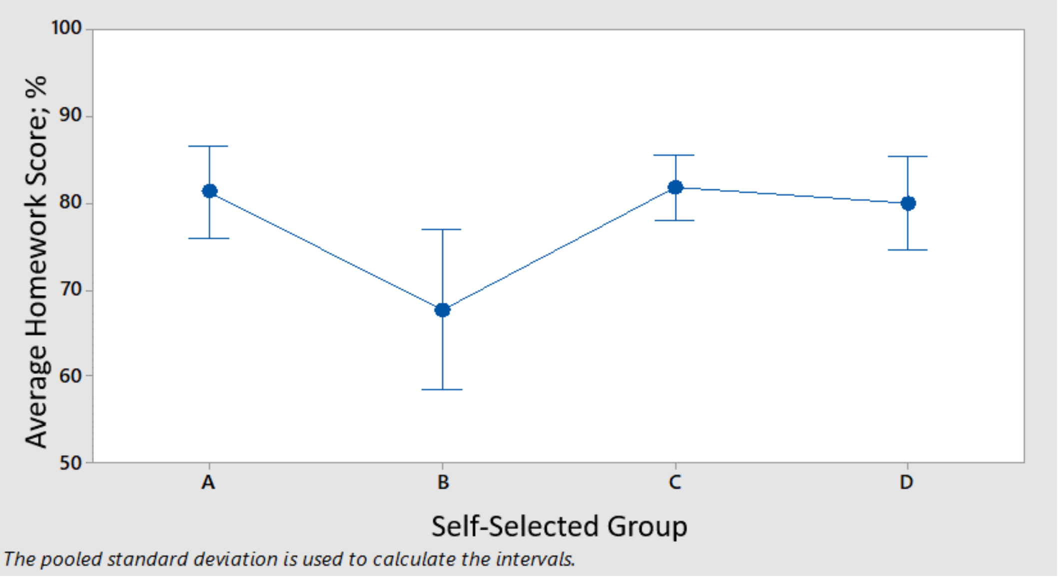


Tukey interval plot of homework scores for self-selected groups, 2013; ANOVA output: F(3, 175) = 2.15, $p < 0.097$

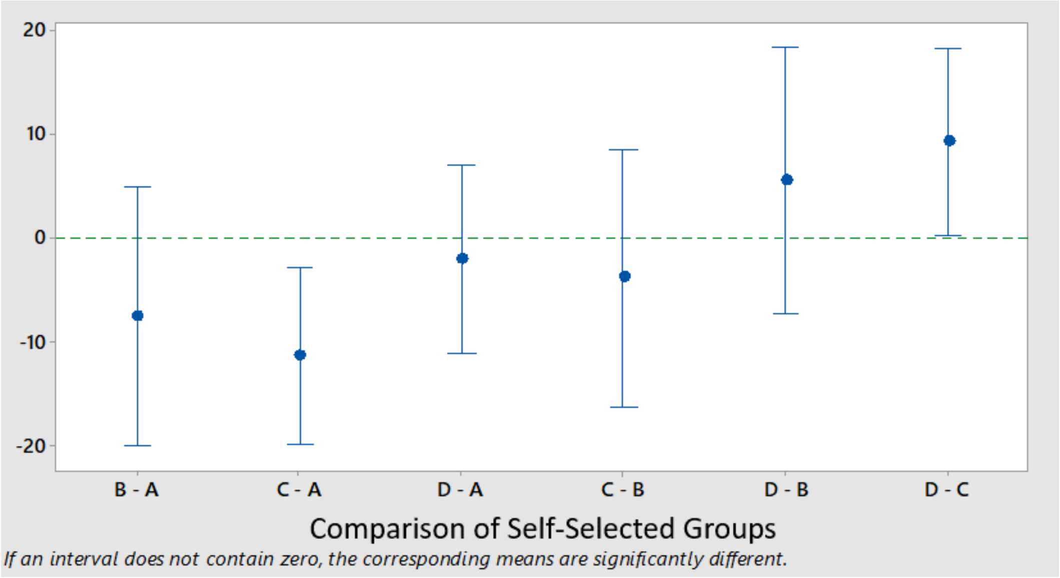
Average spring semester homework scores by self-selected group, 2013



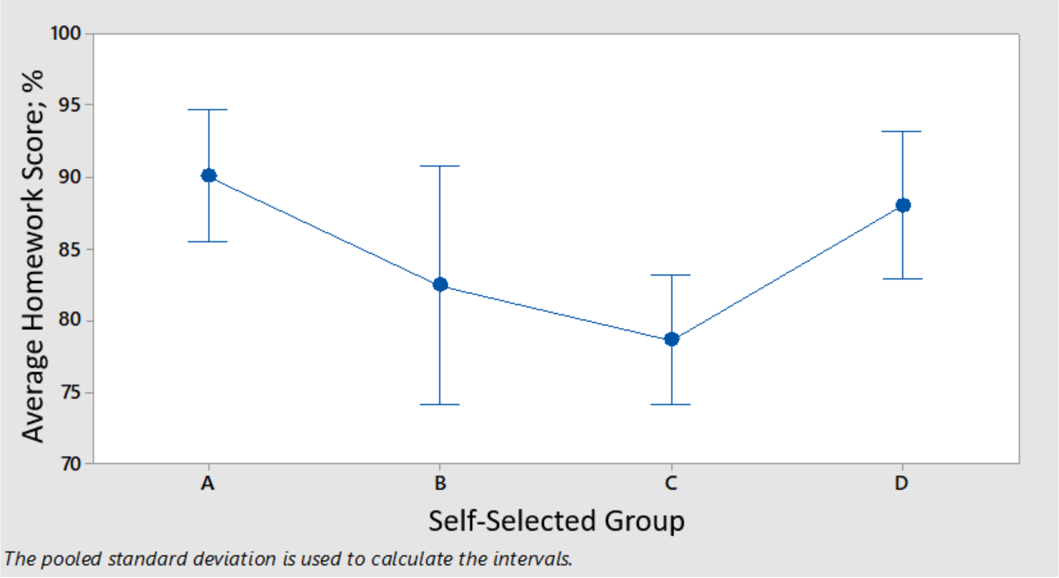
Tukey interval plot of homework scores for self-selected groups, 2014; ANOVA output: F(3, 227) = 2.68, $p < 0.049$



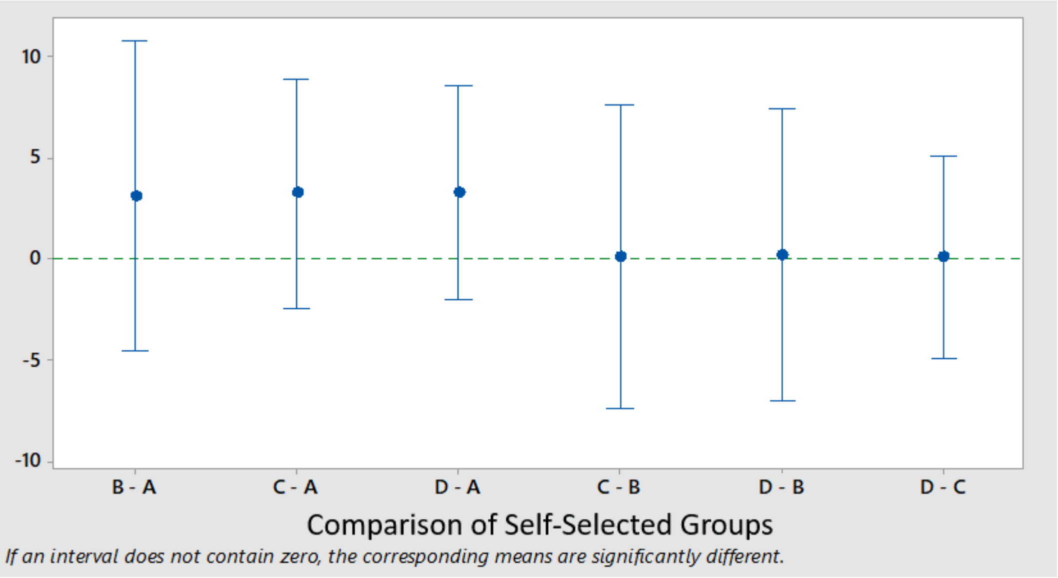
Average spring semester homework scores by self-selected group, 2014



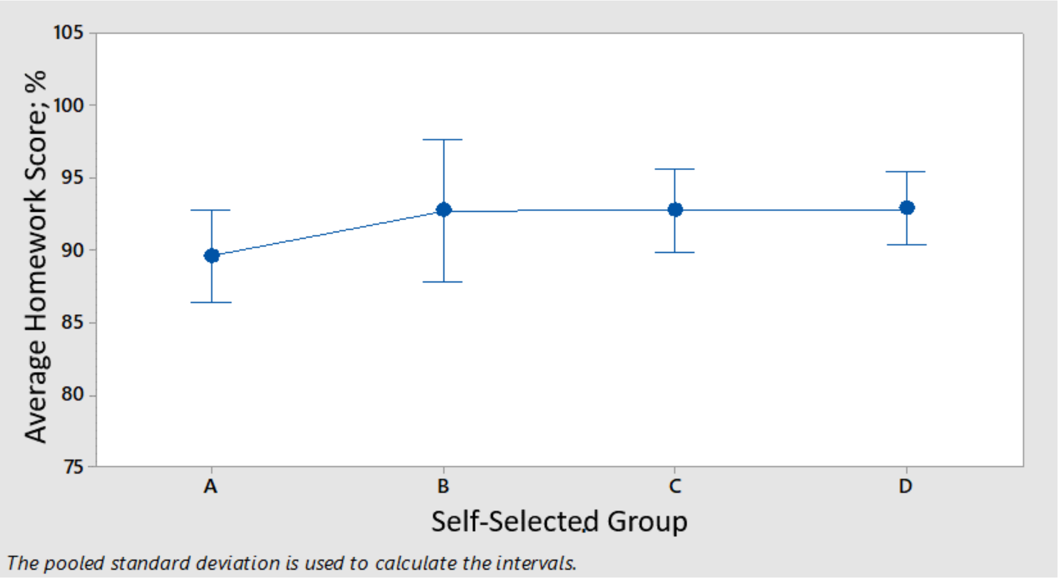
Tukey interval plot of homework scores for self-selected groups, 2015; ANOVA output: F(3, 193) = 4.67, $p < 0.005$



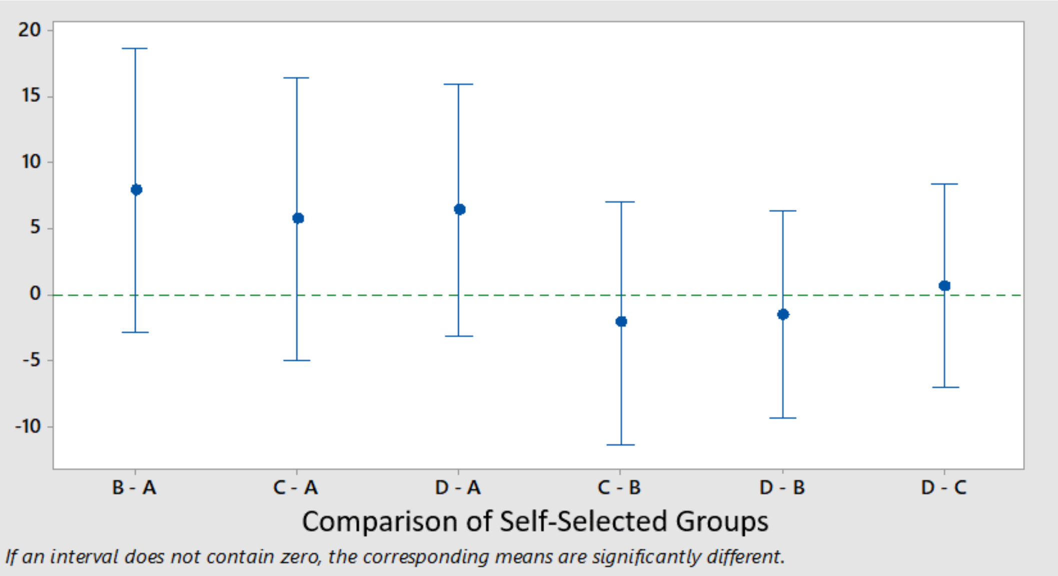
Average spring semester homework scores by self-selected group, 2015



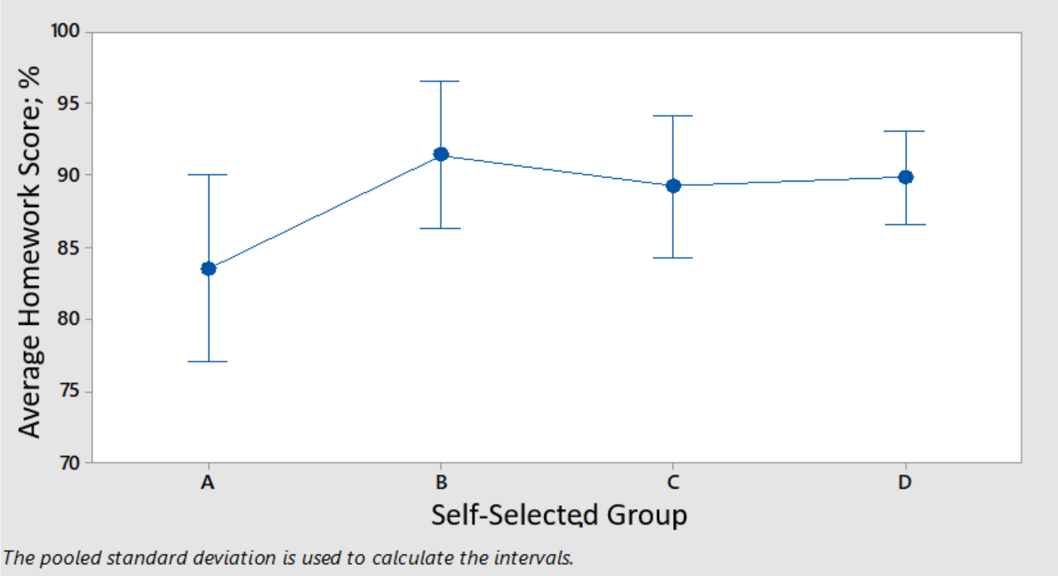
Tukey interval plot of homework scores for self-selected groups, 2016; ANOVA output: $F(3, 235) = 1.02, p < 0.385$



Average spring semester homework scores by self-selected group, 2016



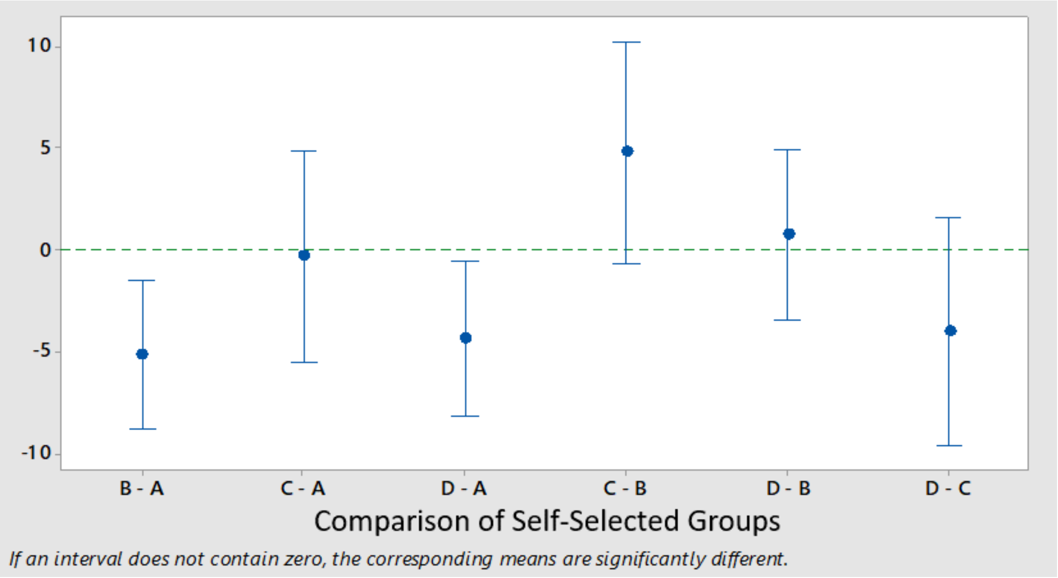
Tukey interval plot of homework scores for self-selected groups, 2017; ANOVA output: F(3, 251) = 1.27, $p < 0.285$



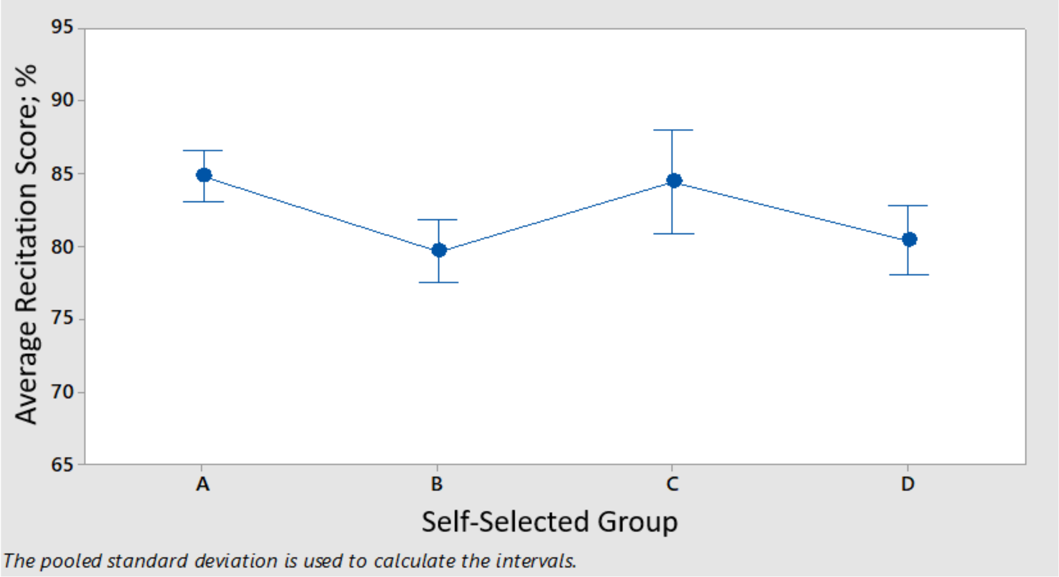
Average spring semester homework scores by self-selected group, 2017

APPENDIX G

FALL SEMESTER RECITATION PERFORMANCE DATA, 2012 – 2016

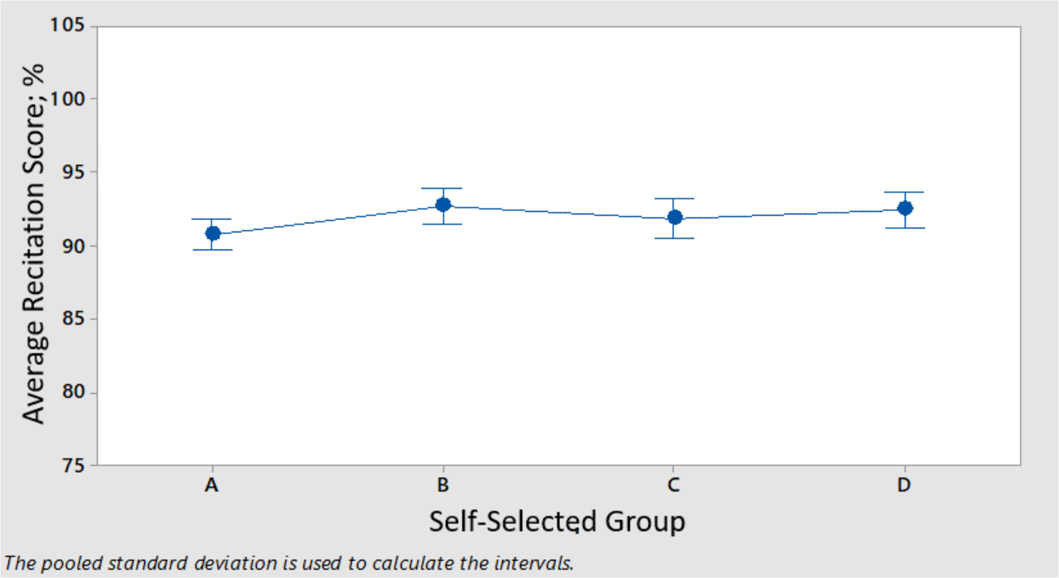


Tukey interval plot of recitation scores for self-selected groups, 2012; ANOVA output: $F(3, 712) = 5.70$, $p < 0.002$

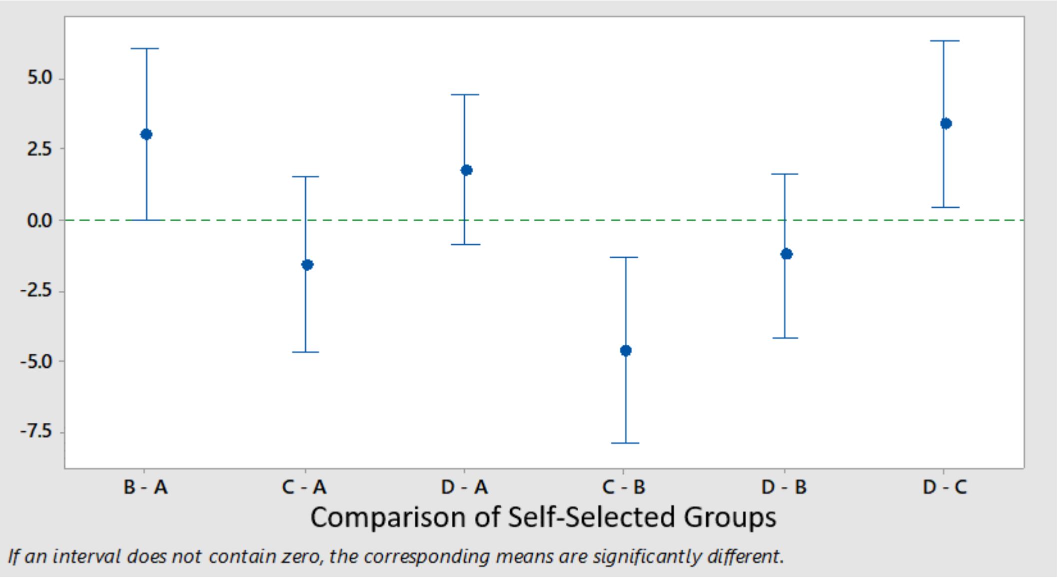


Average fall semester recitation scores by self-selected group, 2012

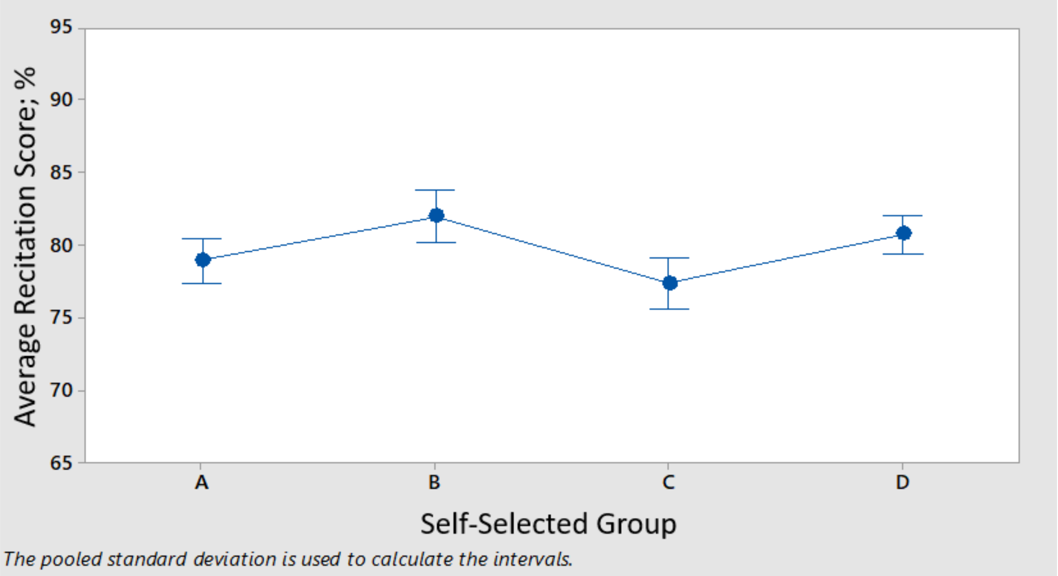
Tukey interval plot of recitation scores for self-selected groups, 2013; ANOVA output: F(3, 718) = 2.48, $p < 0.061$



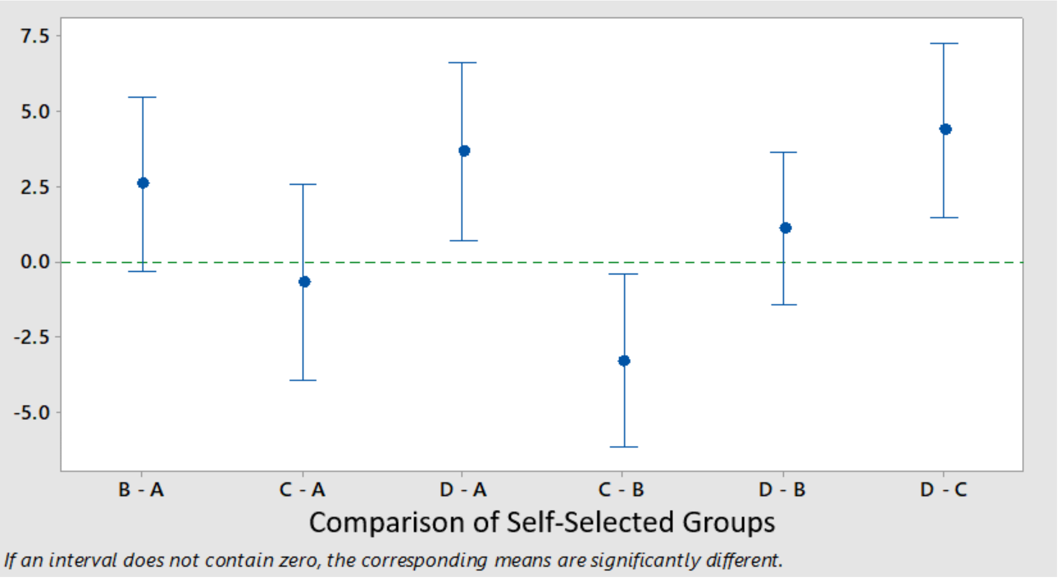
Average fall semester recitation scores by self-selected group, 2013



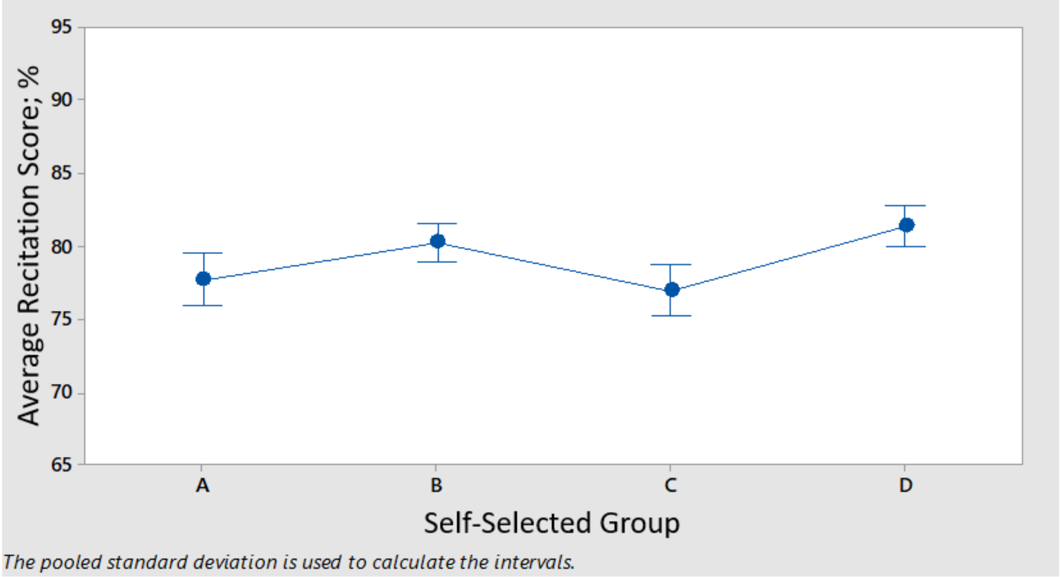
Tukey interval plot of recitation scores for self-selected groups, 2014; ANOVA output: $F(3, 769) = 5.36$, $p < 0.002$



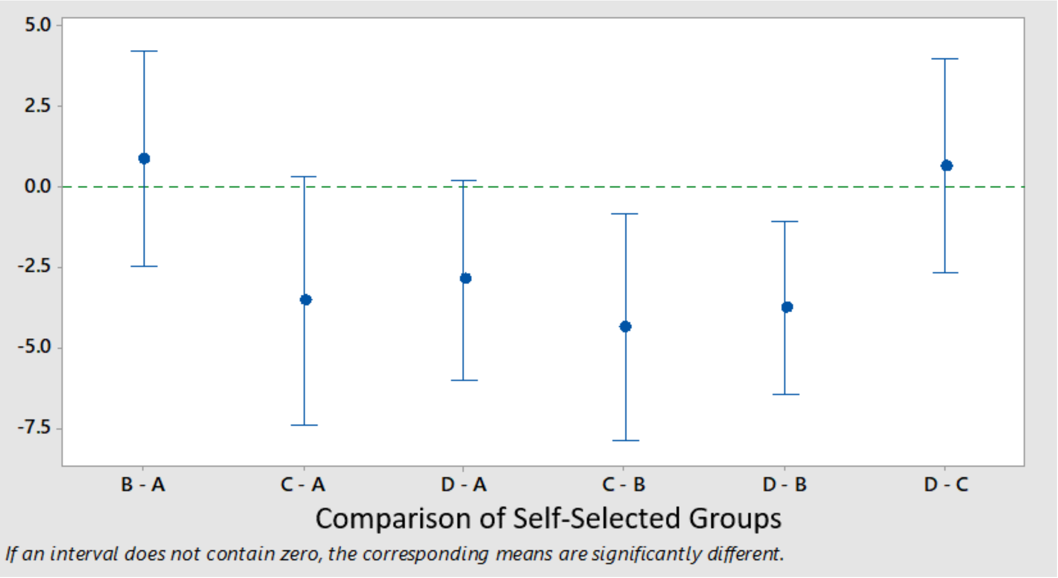
Average fall semester recitation scores by self-selected group, 2014



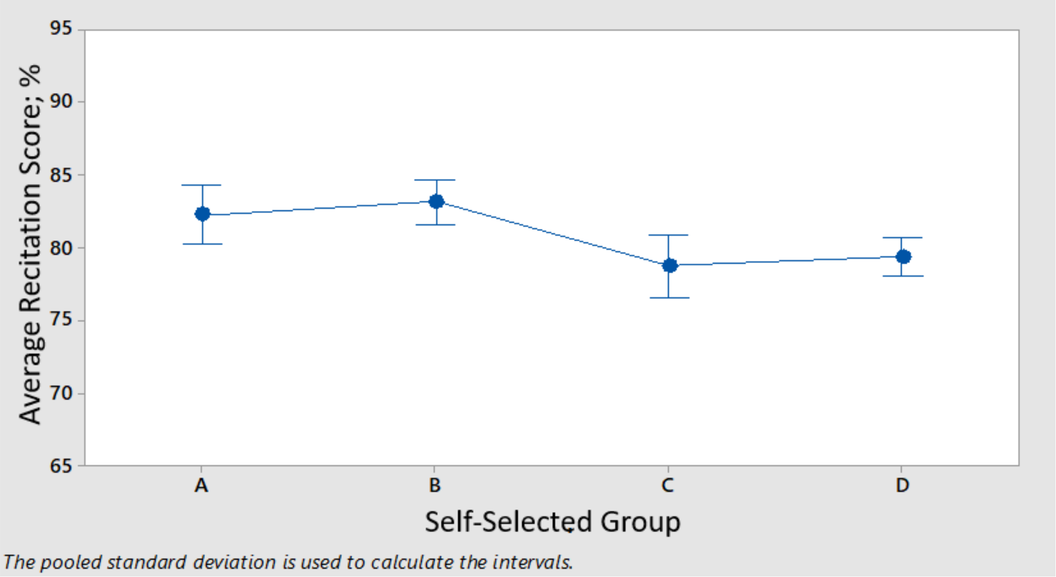
Tukey interval plot of recitation scores for self-selected groups, 2015; ANOVA output: F(3, 851) = 6.86, p < 0.001



Average fall semester recitation scores by self-selected group, 2015



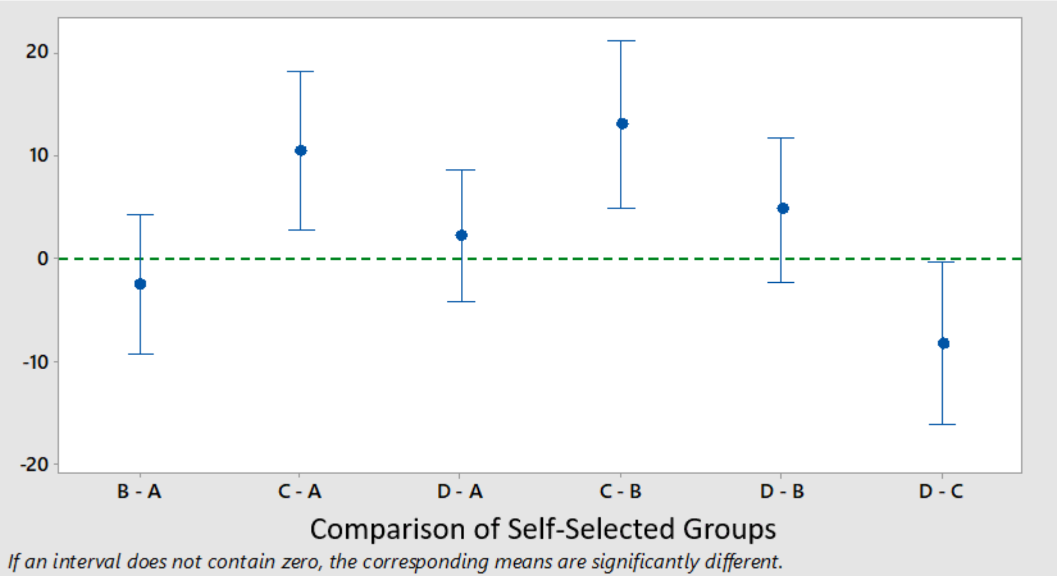
Tukey interval plot of recitation scores for self-selected groups, 2016; ANOVA output: F(3, 805) = 6.14, $p < 0.001$



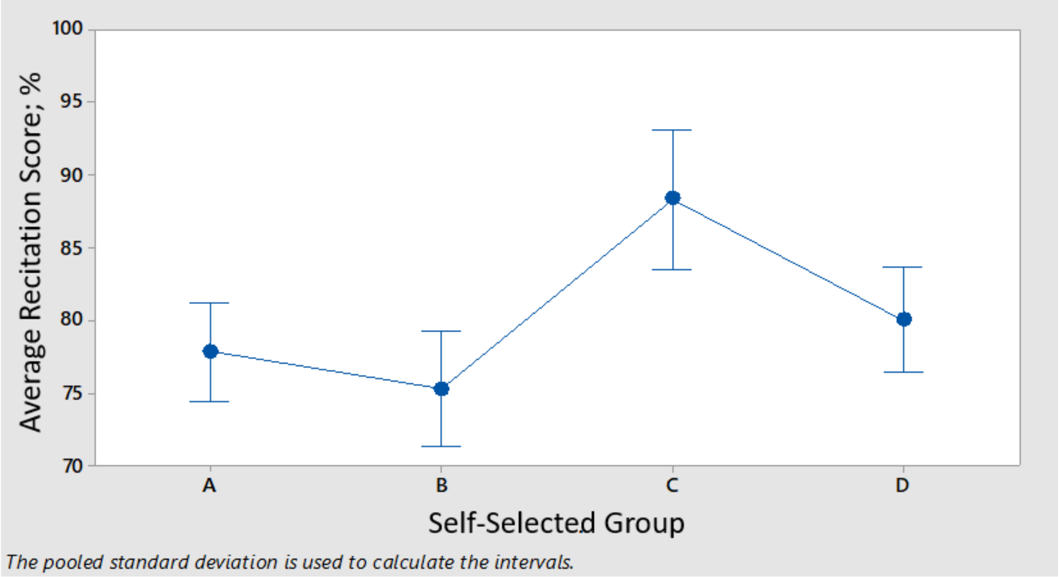
Average fall semester recitation scores by self-selected group, 2016

APPENDIX H

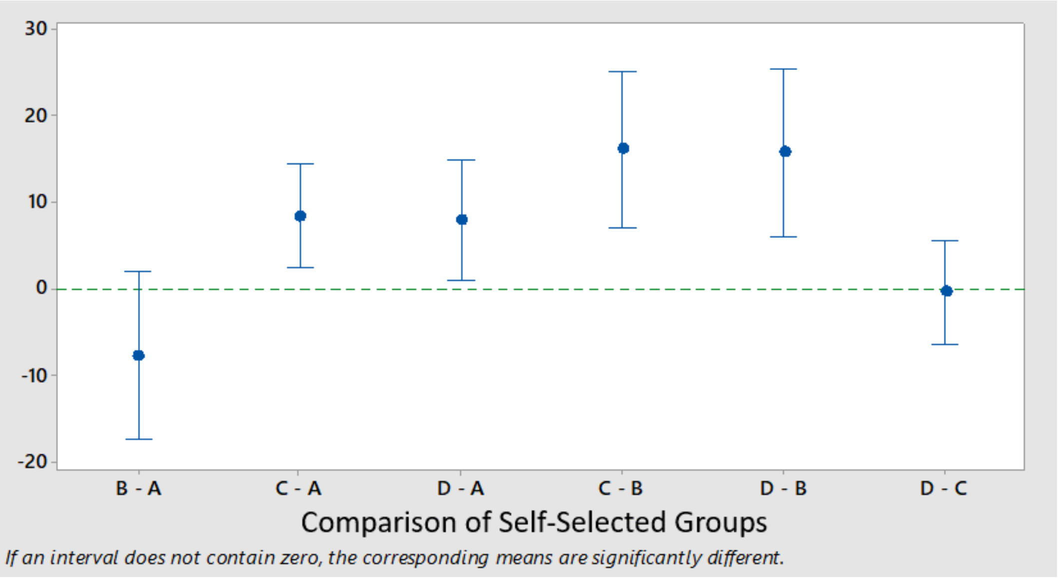
SPRING SEMESTER RECITATION PERFORMANCE DATA, 2013 - 2017



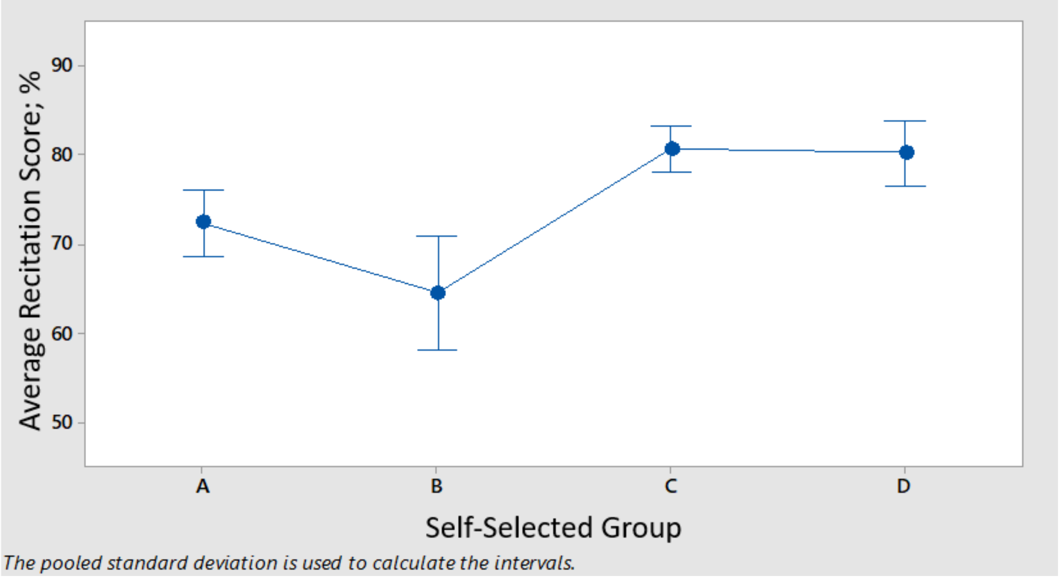
Tukey interval plot of recitation scores for self-selected groups, 2013; ANOVA output: $F(3, 172) = 6.28, p < 0.001$



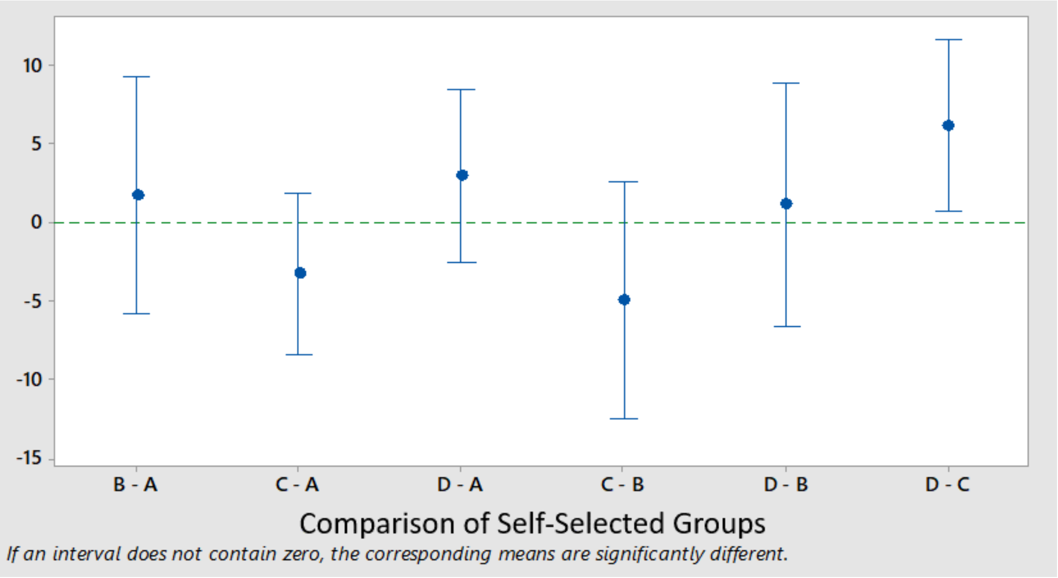
Average spring semester recitation scores by self-selected group, 2013



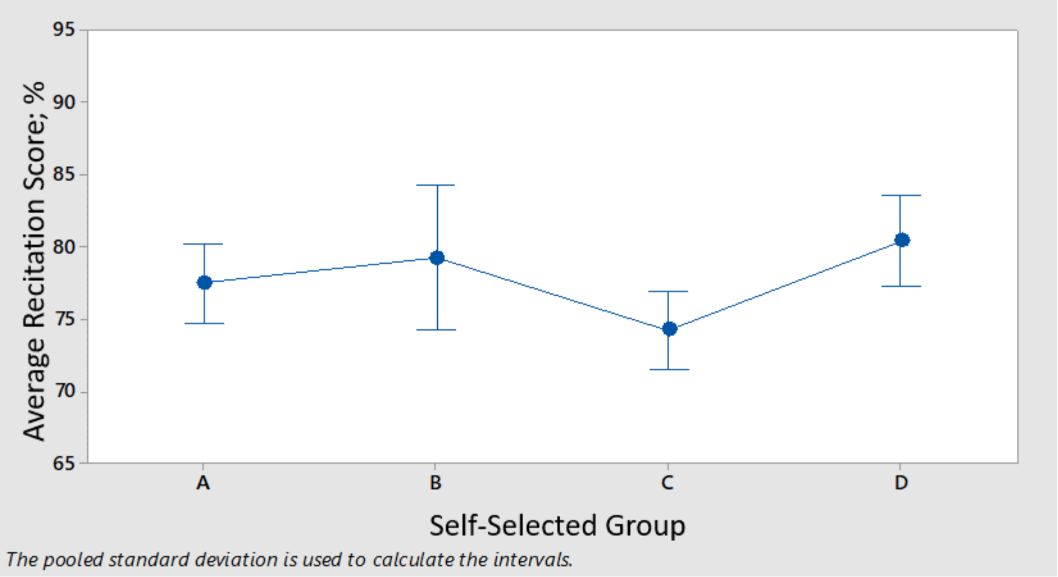
Tukey interval plot of recitation scores for self-selected groups, 2014; ANOVA output: F(3, 227) = 10.34, $p < 0.001$



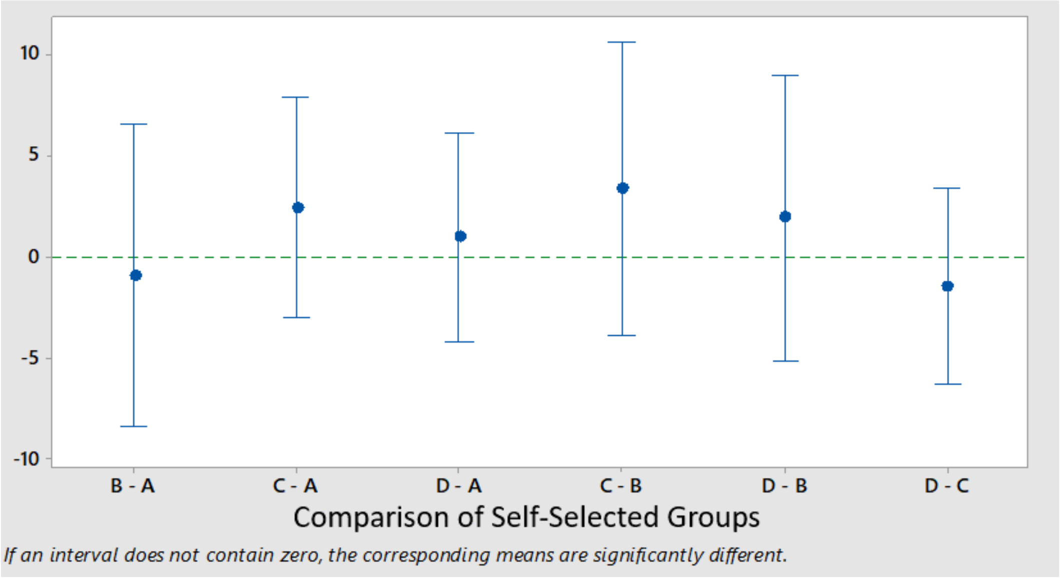
Average spring semester recitation scores by self-selected group, 2014



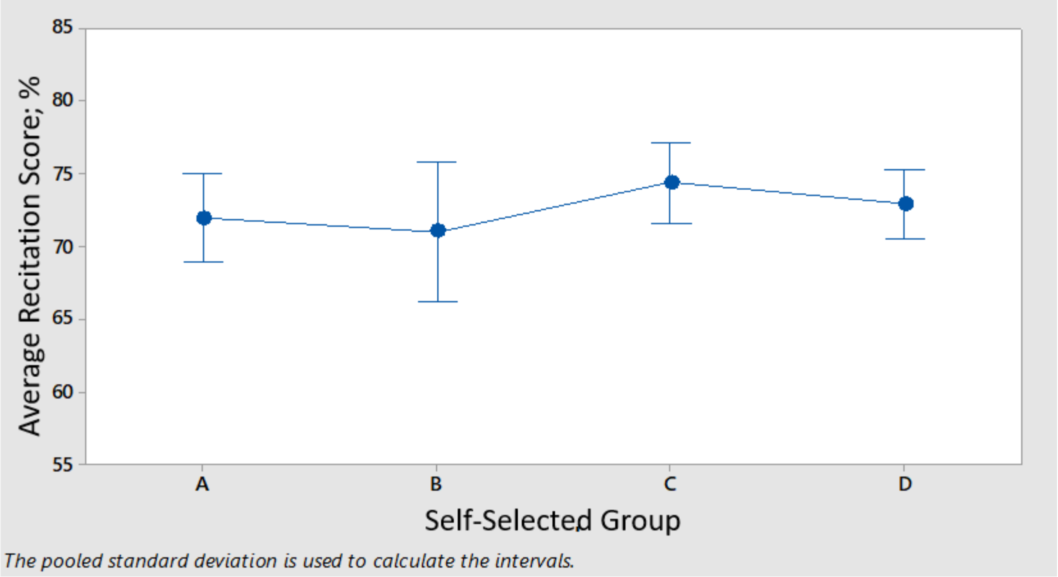
Tukey interval plot of recitation scores for self-selected groups, 2015; ANOVA output: F(3, 193) = 3.11, $p < 0.028$



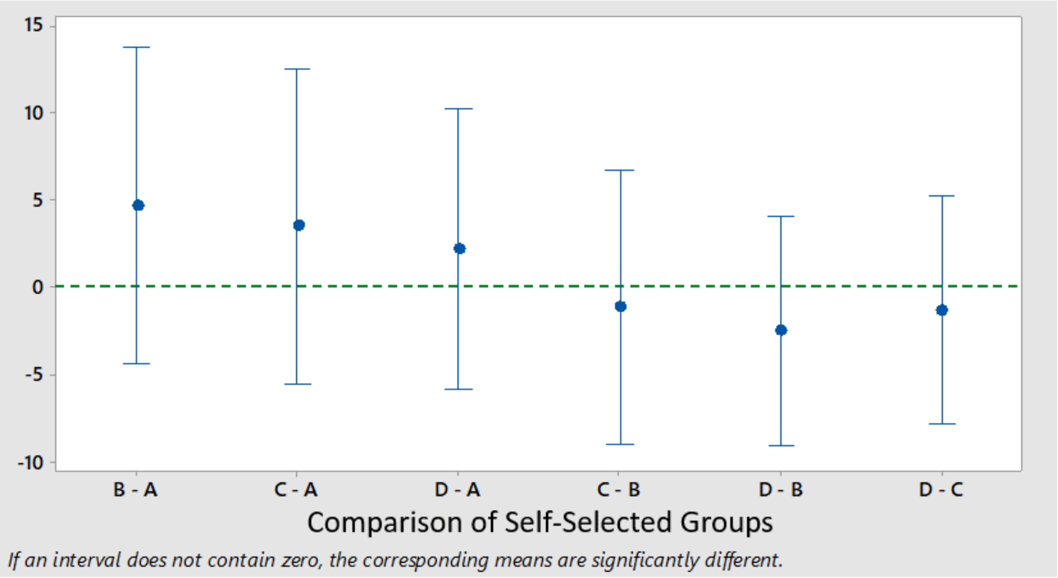
Average spring semester recitation scores by self-selected group, 2015



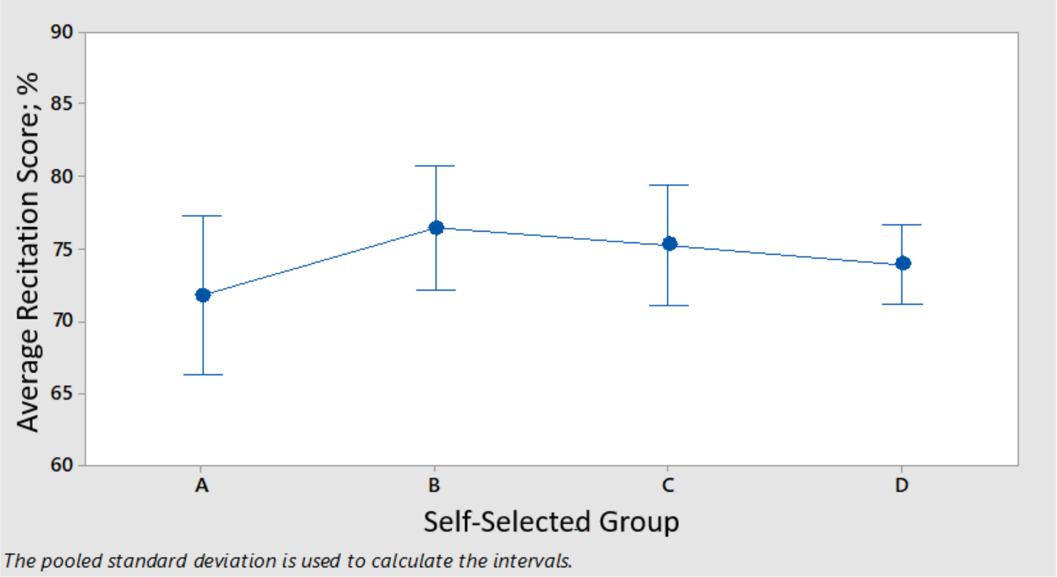
Tukey interval plot of recitation scores for self-selected groups, 2016; ANOVA output: F(3, 235) = 0.69, p < 0.560



Average spring semester recitation scores by self-selected group, 2016



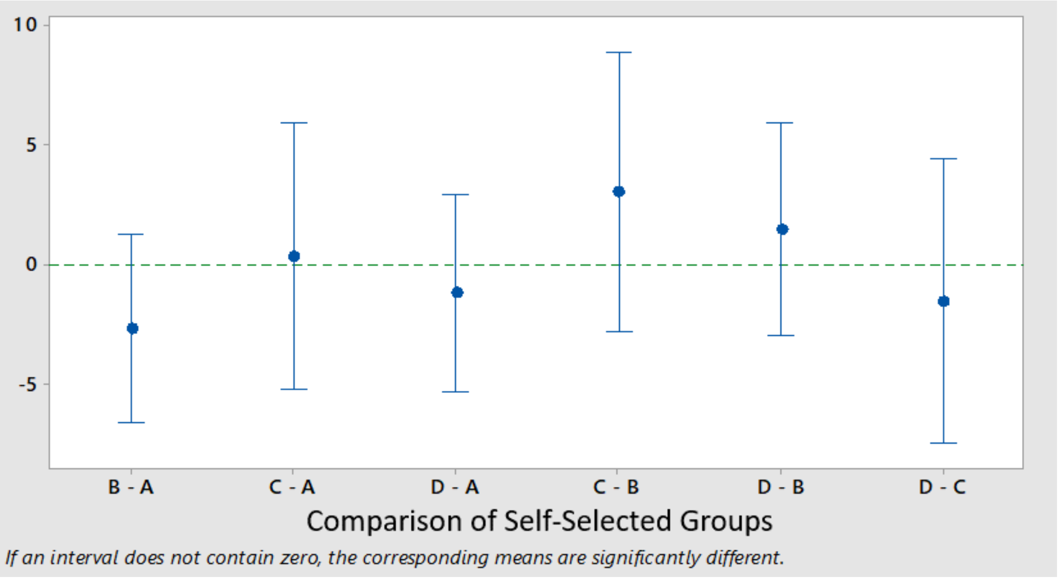
Tukey interval plot of recitation scores for self-selected groups, 2017; ANOVA output: F(3, 251) = 0.67, p < 0.571



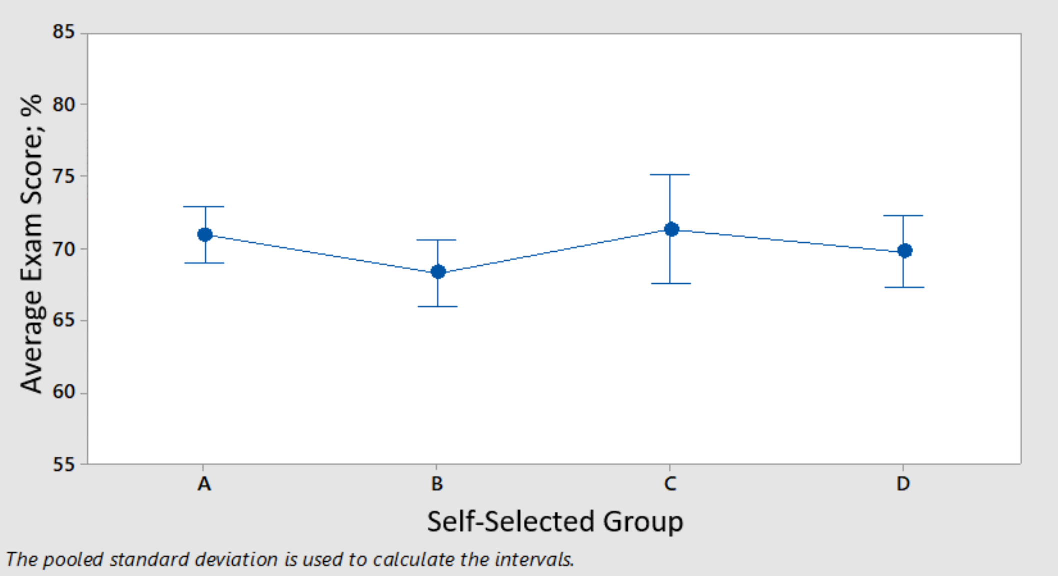
Average spring semester recitation scores by self-selected group, 2017

APPENDIX I

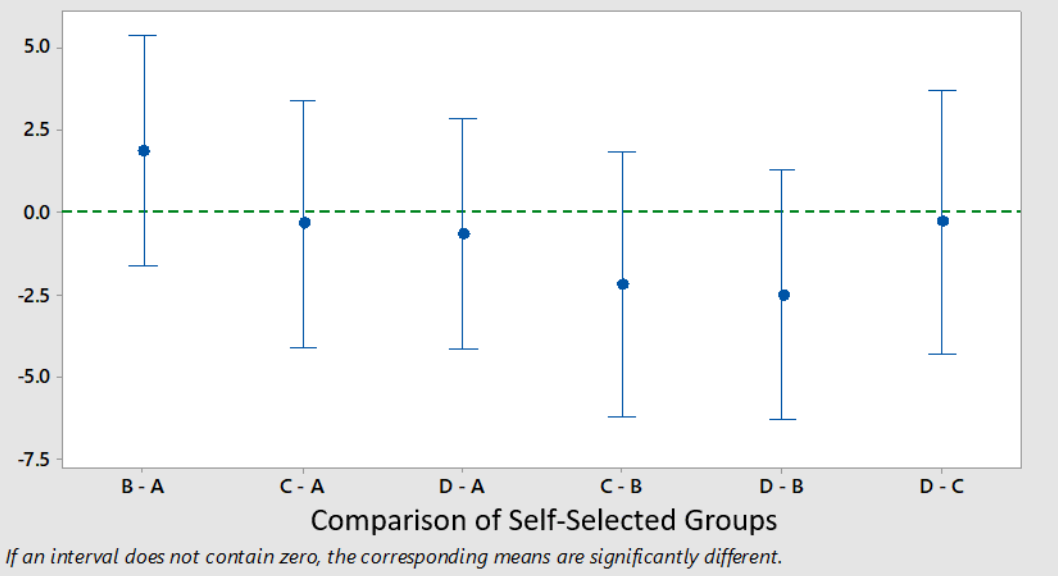
FALL SEMESTER EXAM PERFORMANCE DATA, 2012 - 2016



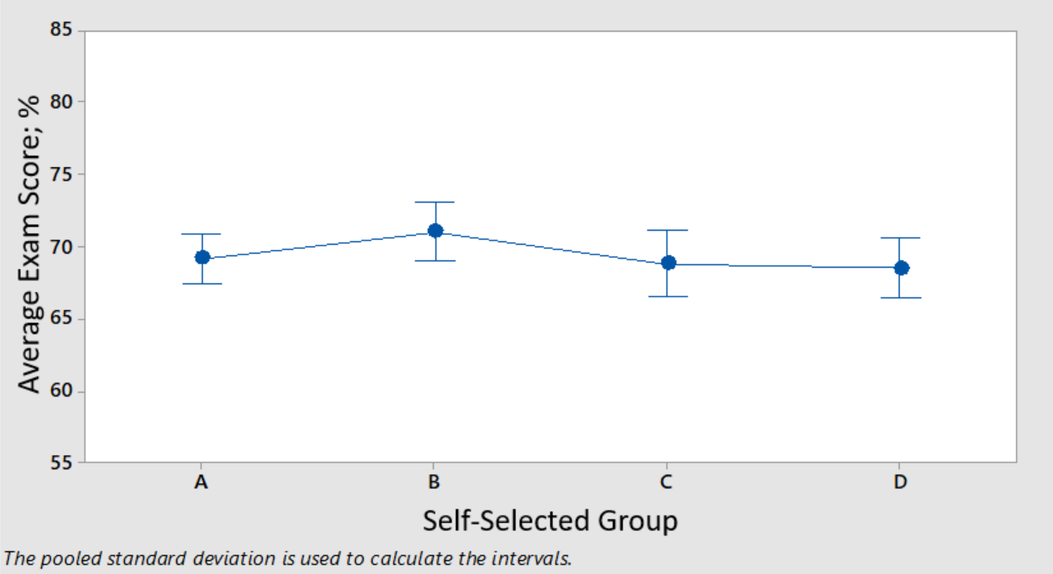
Tukey interval plot of average exam scores for self-selected groups, 2012; ANOVA output: F(3, 712) = 1.20, $p < 0.310$



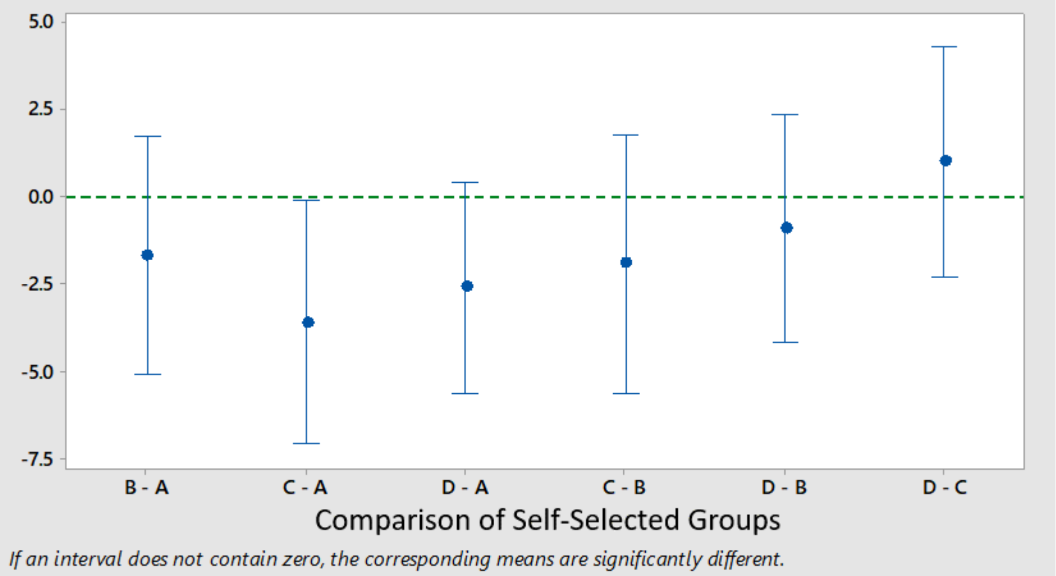
Average fall semester exam scores by self-selected group, 2012



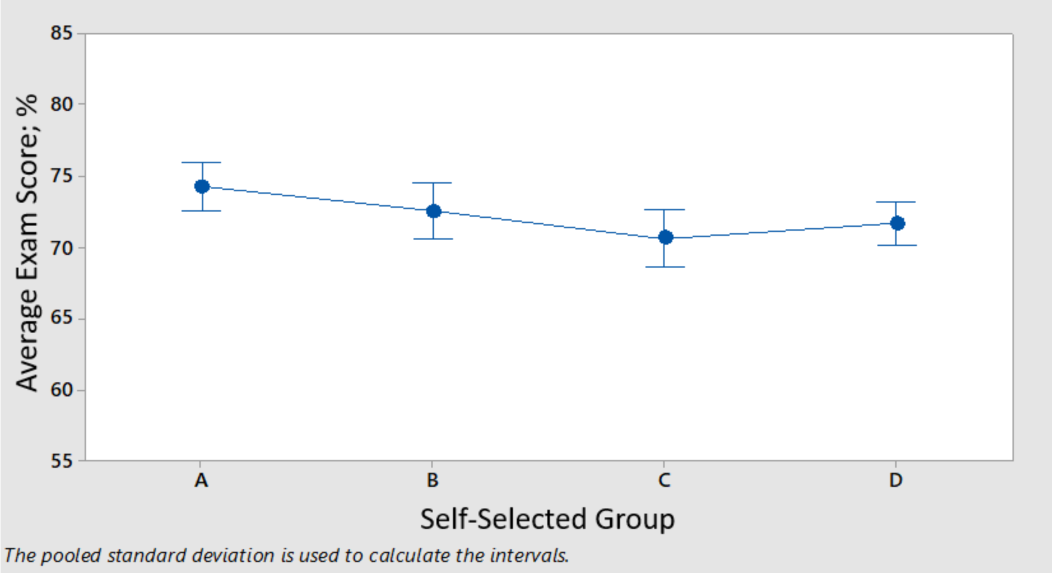
Tukey interval plot of average exam scores for self-selected groups, 2013;
ANOVA output: $F(3, 718) = 1.17$, $p < 0.321$



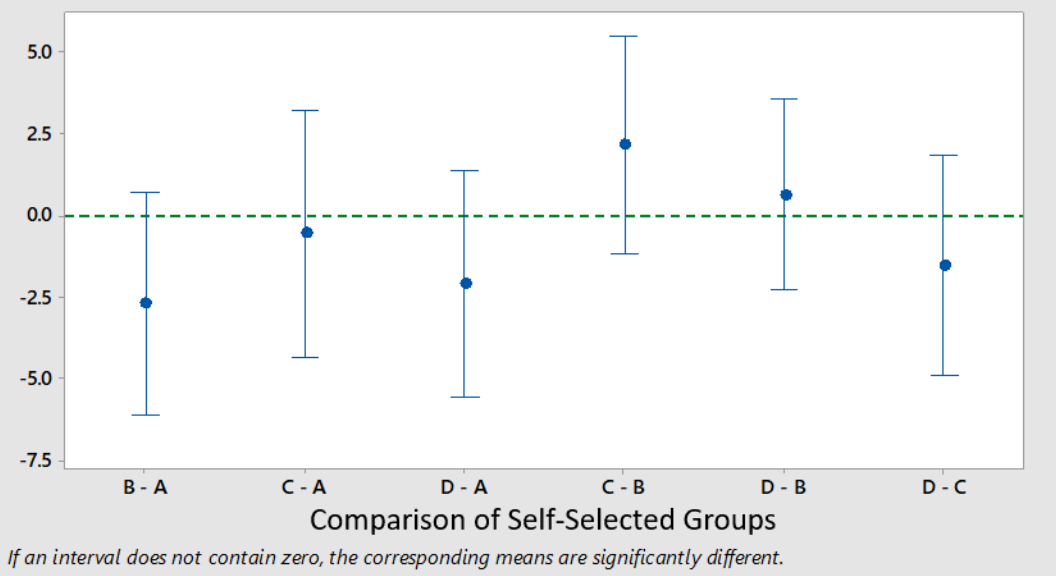
Average fall semester exam scores by self-selected group, 2013



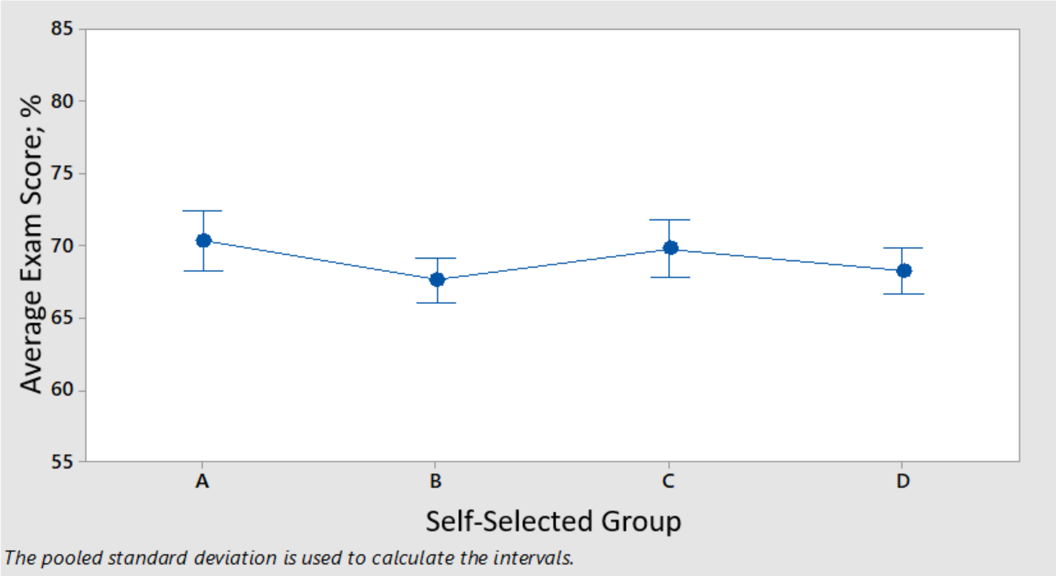
Tukey interval plot of average exam scores for self-selected groups, 2014; ANOVA output: $F(3, 769) = 2.73$, $p < 0.044$



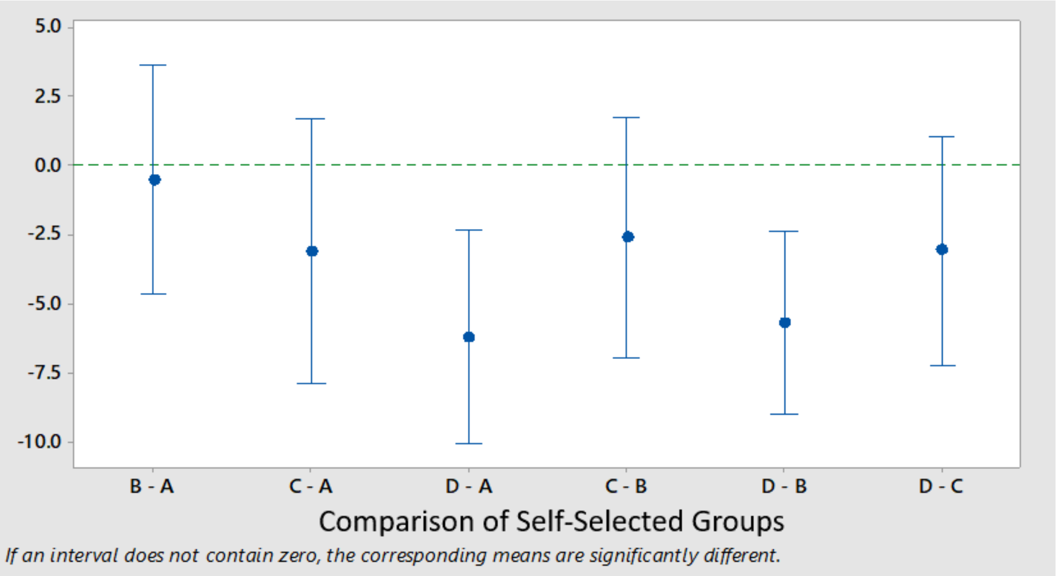
Average fall semester exam scores by self-selected group, 2014



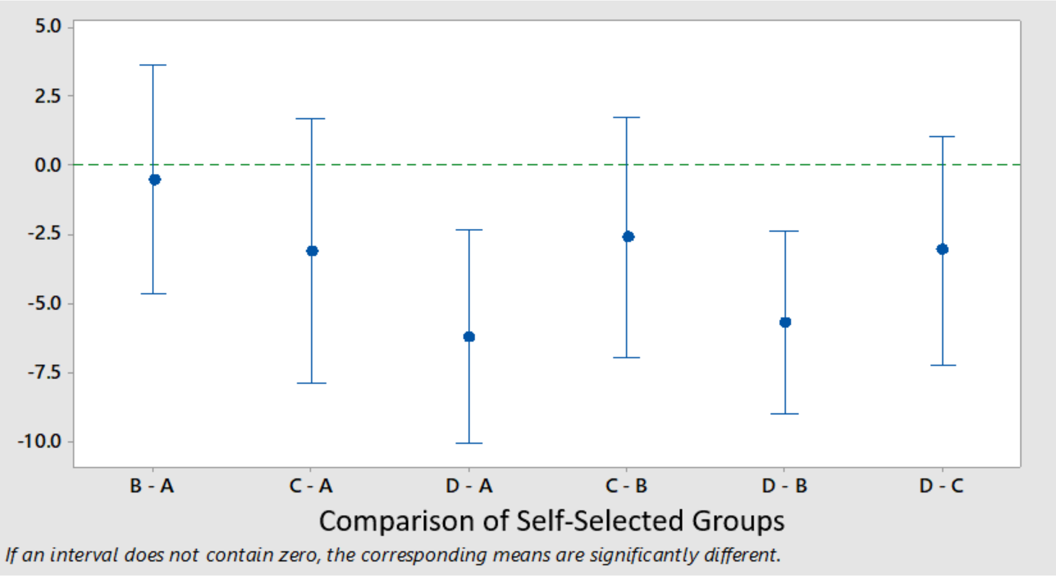
Tukey interval plot of average exam scores for self-selected groups, 2015; ANOVA output: F(3, 851) = 1.87, $p < 0.134$



Average fall semester exam scores by self-selected group, 2015



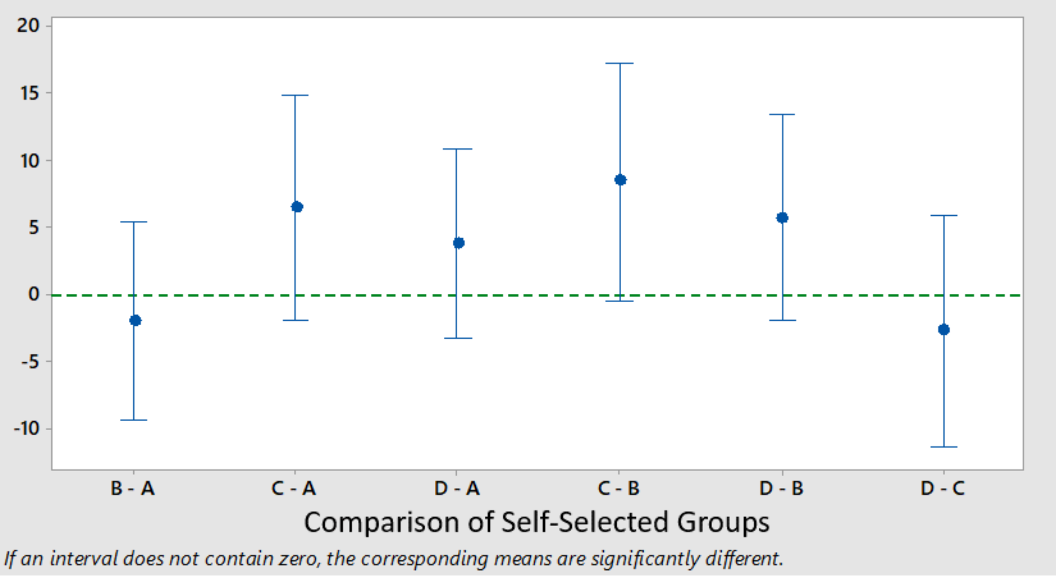
Tukey interval plot of average exam scores for self-selected groups, 2016;
ANOVA output: F(3, 805) = 8.96, $p < 0.001$



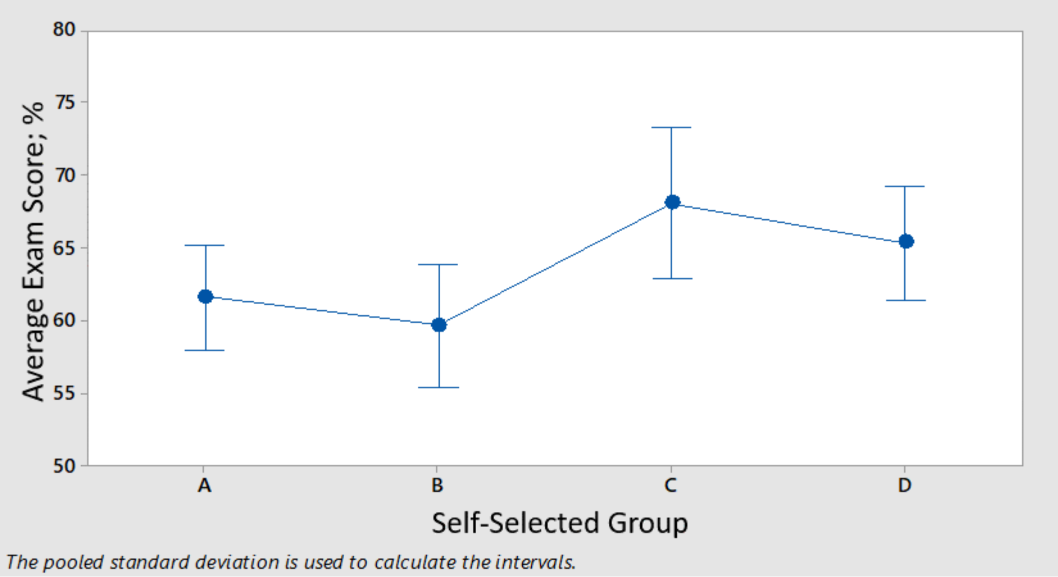
Average fall semester exam scores by self-selected group, 2016

APPENDIX J

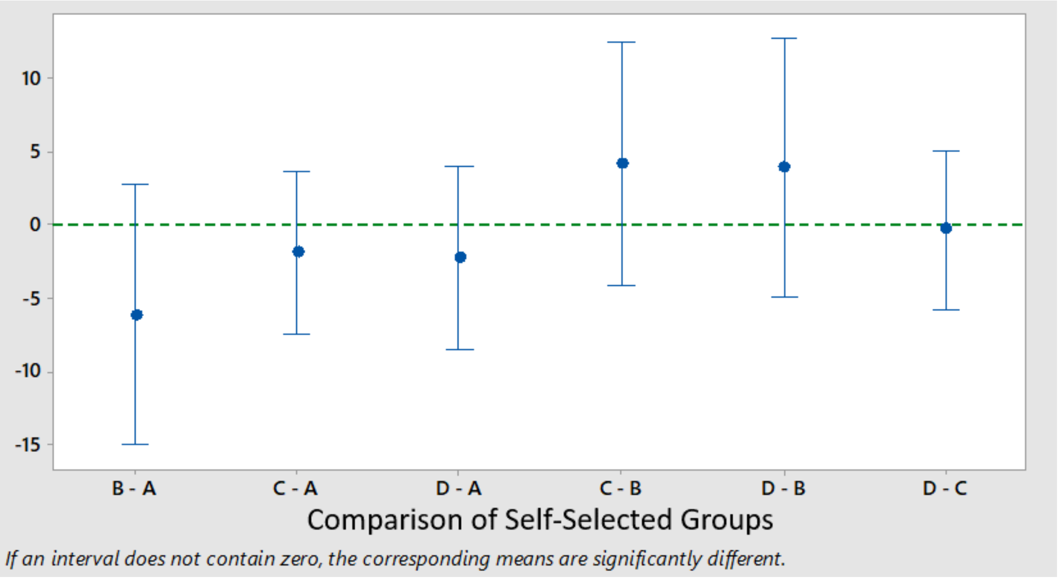
SPRING SEMESTER EXAM PERFORMANCE DATA, 2013 – 2017



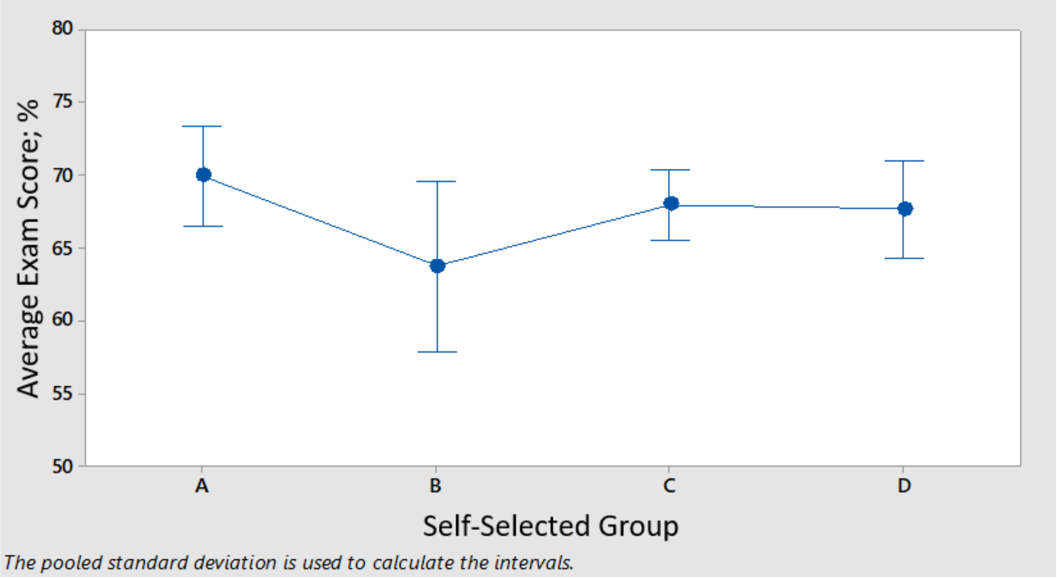
Tukey interval plot of average exam scores for self-selected groups, 2013;
ANOVA output: F(3, 175) = 2.67, $p < 0.050$



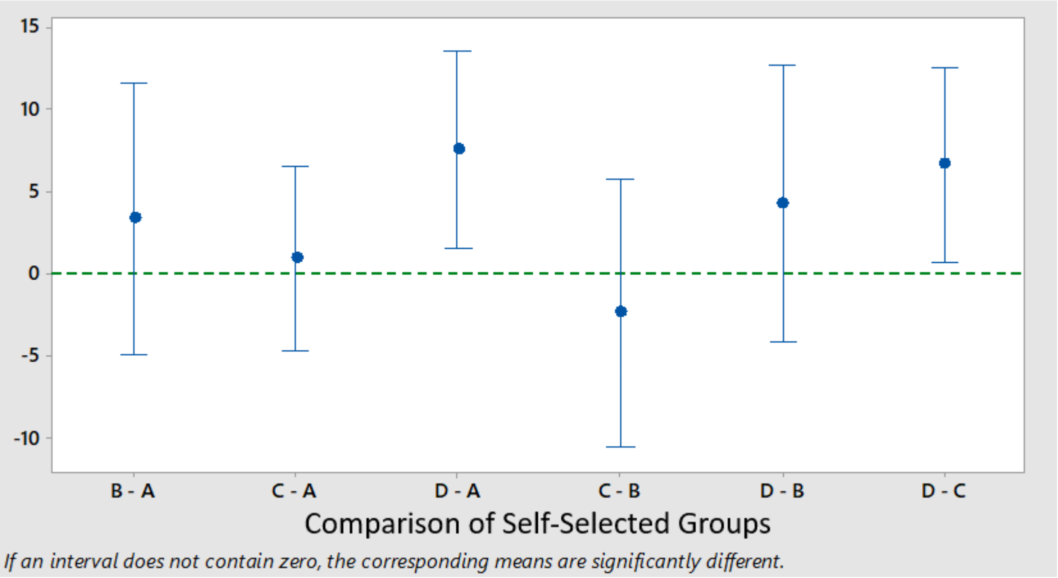
Average spring semester exam scores by self-selected group, 2013



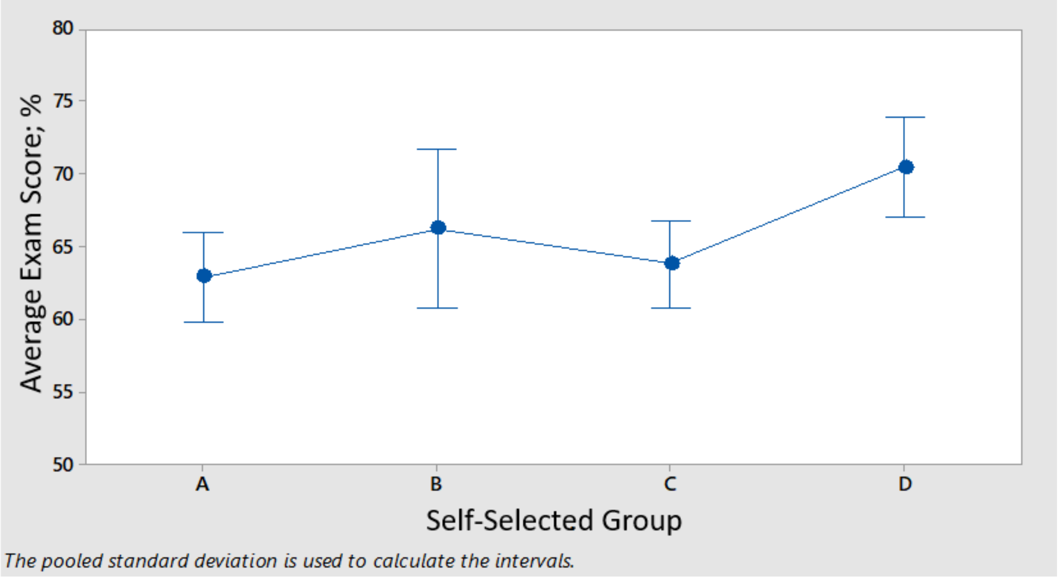
Tukey interval plot of average exam scores for self-selected groups, 2014; ANOVA output: F(3, 227) = 1.11, $p < 0.349$



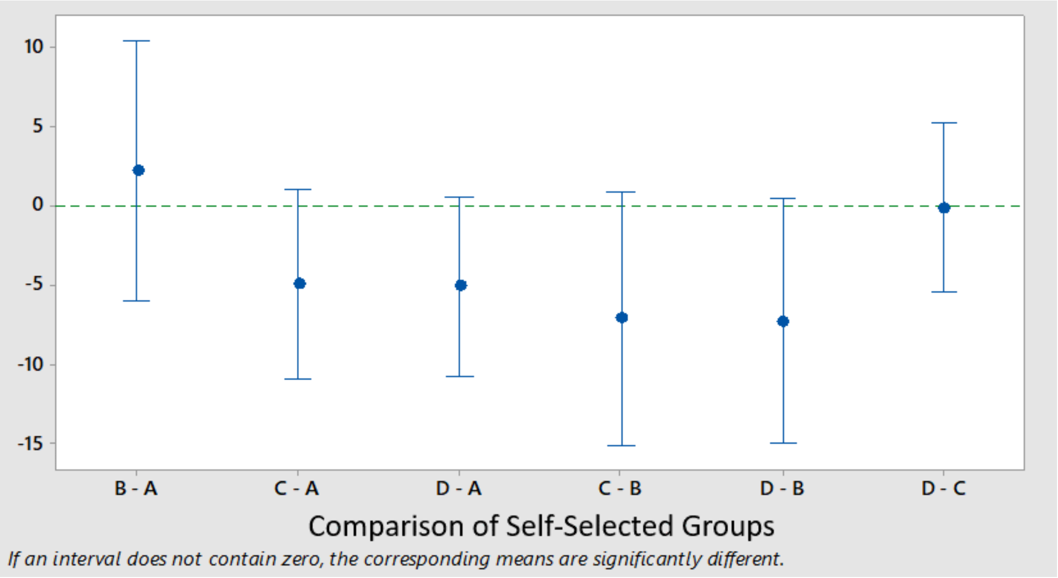
Average spring semester exam scores by self-selected group, 2014



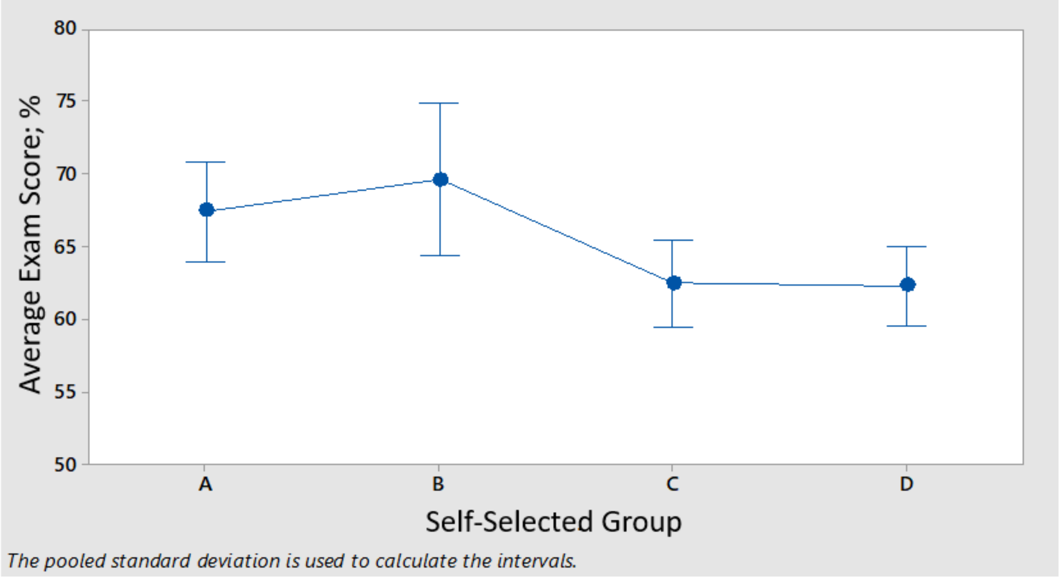
Tukey interval plot of average exam scores for self-selected groups, 2015; ANOVA output: F(3, 193) = 4.17, $p < 0.008$



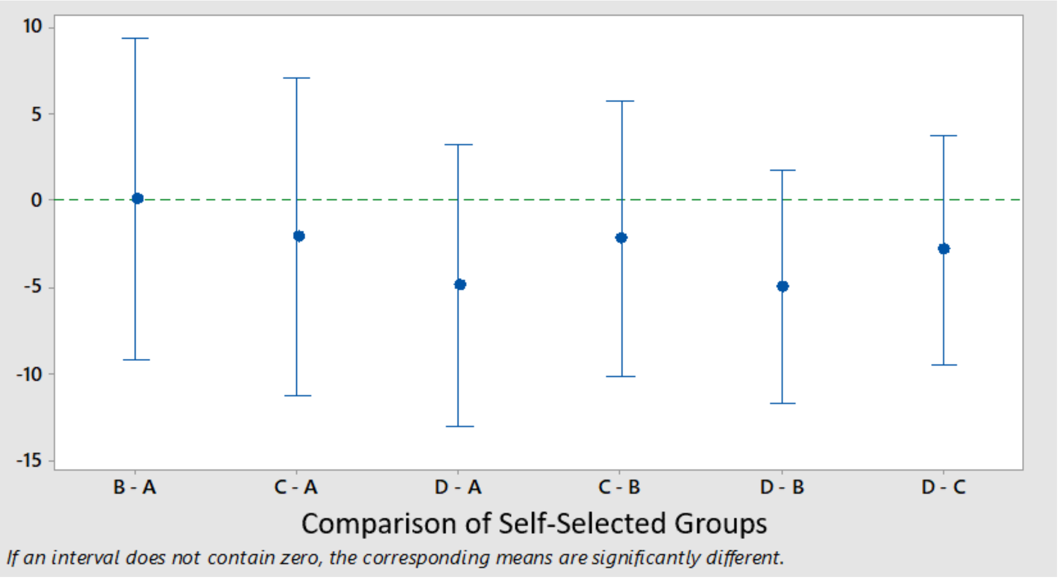
Average spring semester exam scores by self-selected group, 2015



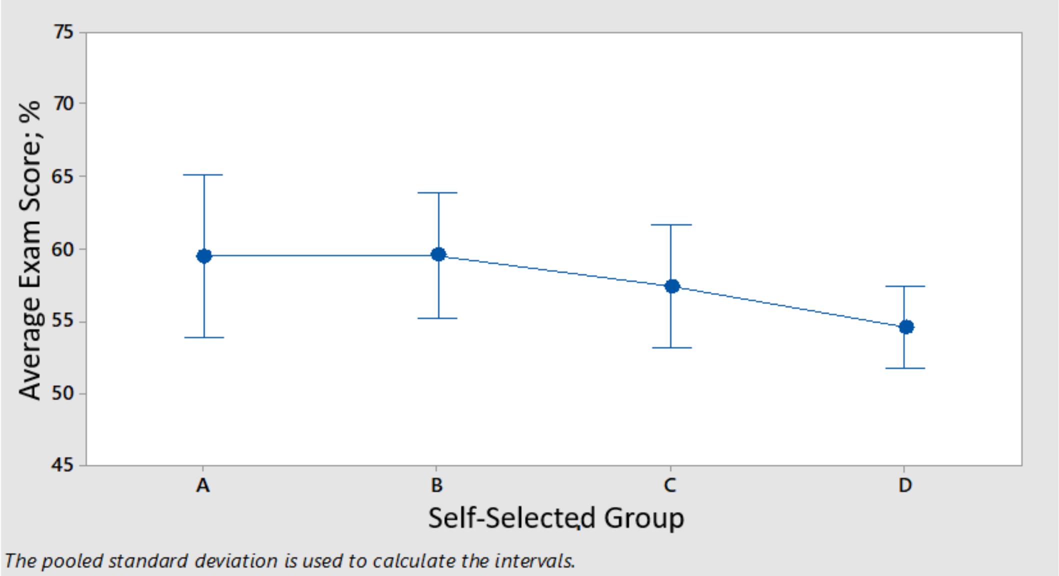
Tukey interval plot of average exam scores for self-selected groups, 2016;
ANOVA output: F(3, 235) = 3.64, $p < 0.014$



Average spring semester exam scores by self-selected group, 2016



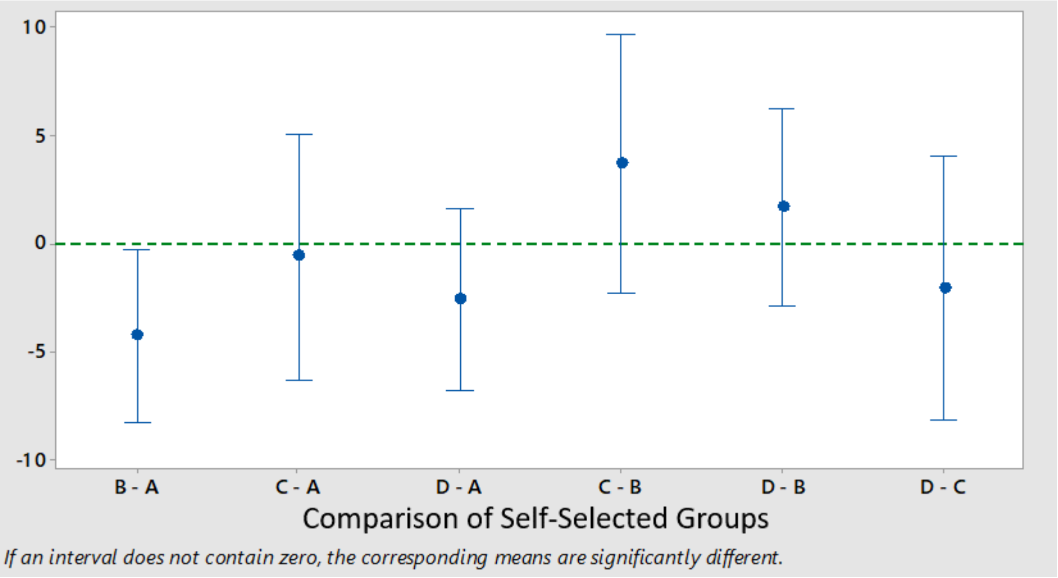
Tukey interval plot of average exam scores for self-selected groups, 2017; ANOVA output: F(3, 251) = 1.65, $p < 0.180$



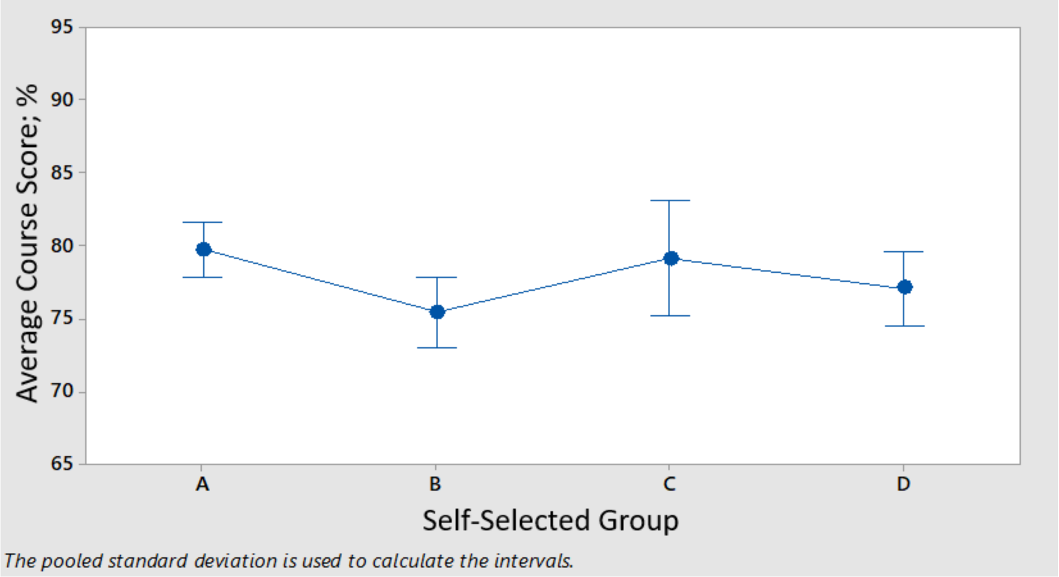
Average spring semester exam scores by self-selected group, 2017

APPENDIX K

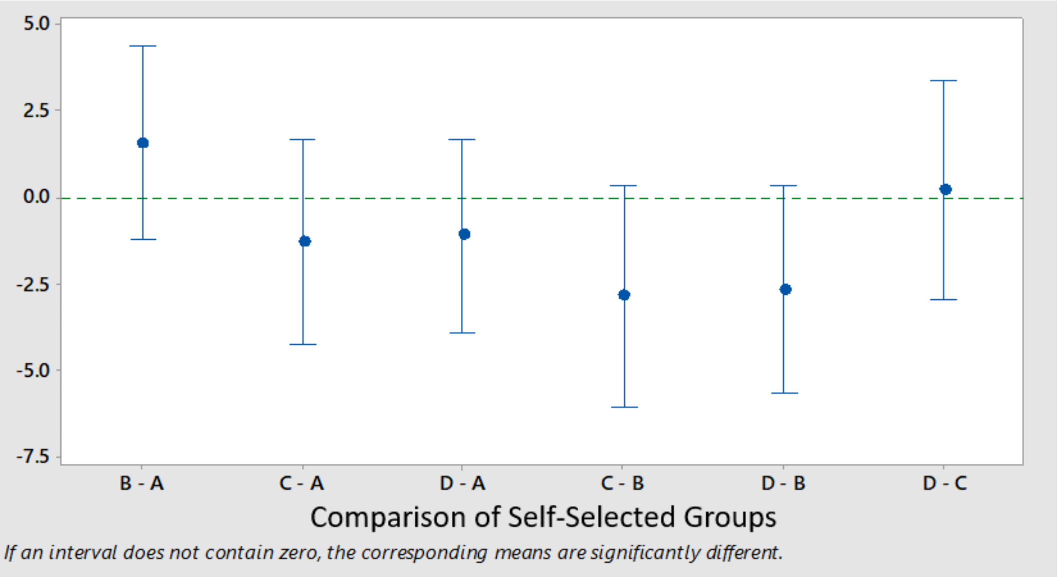
FALL SEMESTER OVERALL PERFORMANCE DATA, 2012 - 2016



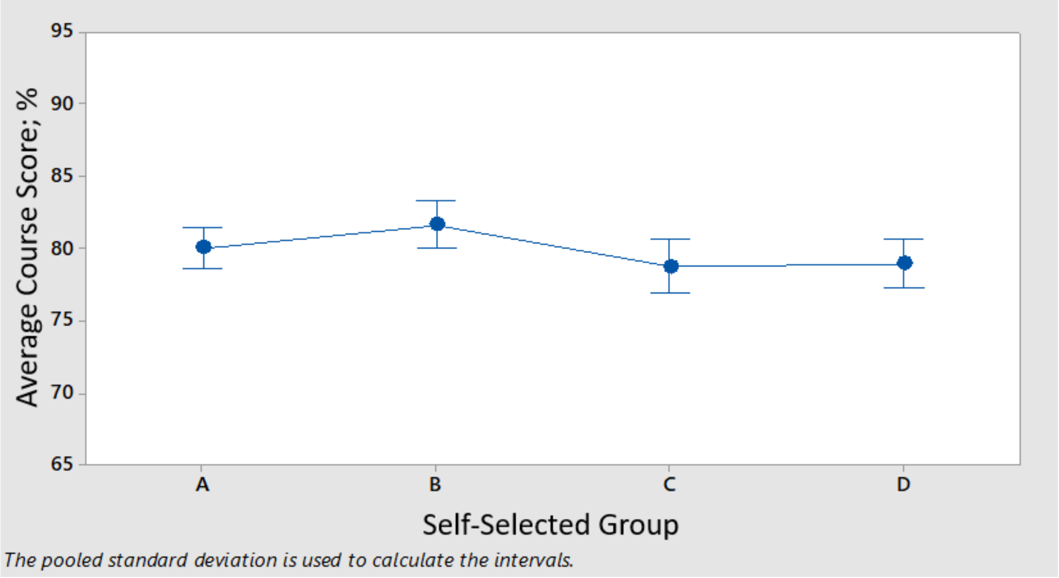
Tukey interval plot of average final course scores for self-selected groups, 2012; ANOVA output: $F(3, 712) = 2.77, p < 0.042$



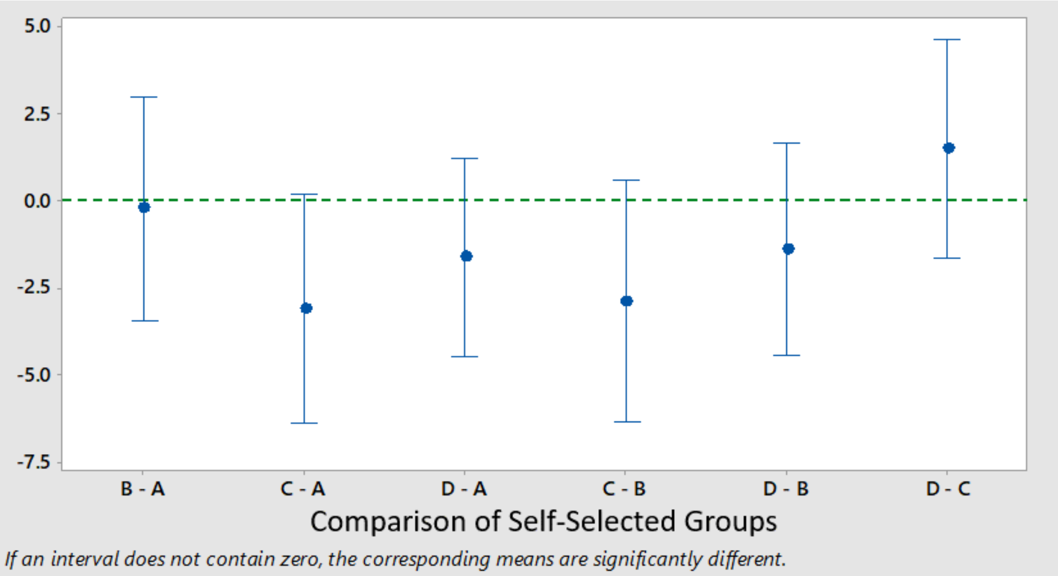
Average fall semester final course scores by self-selected group, 2012



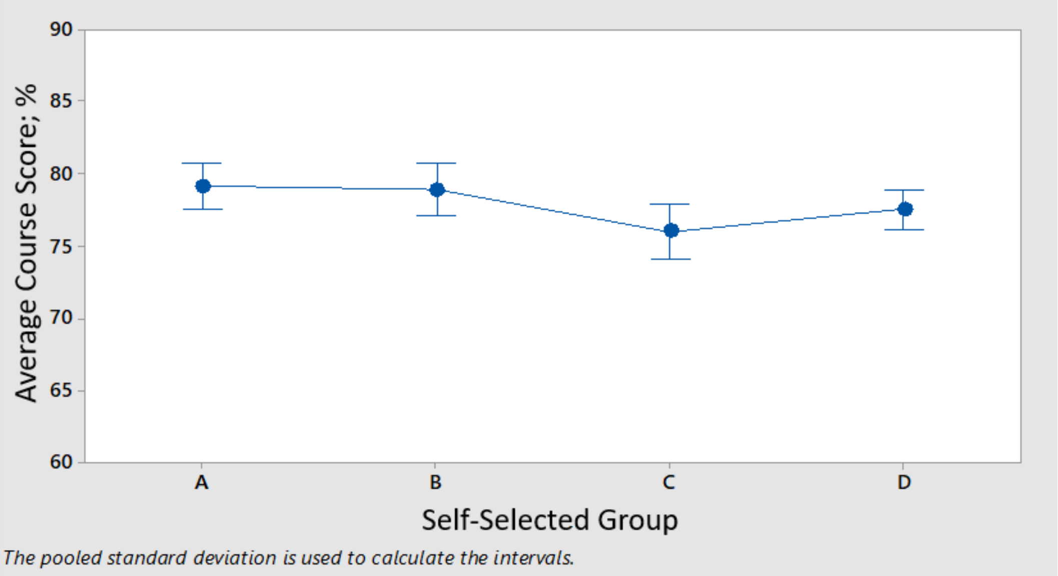
Tukey interval plot of average final course scores for self-selected groups, 2013; ANOVA output: F(3, 718) = 2.40, $p < 0.068$



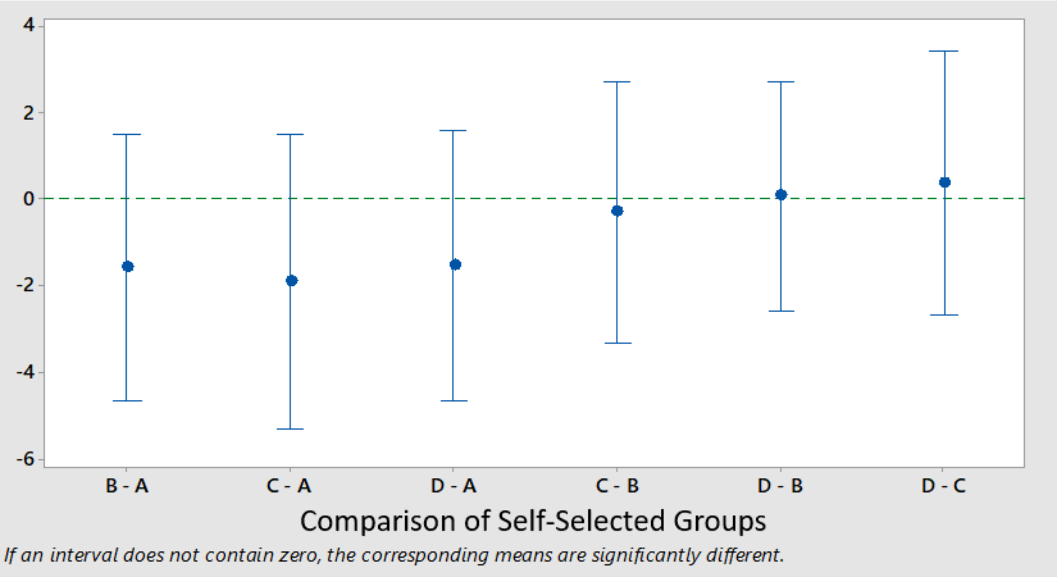
Average fall semester final course scores by self-selected group, 2013



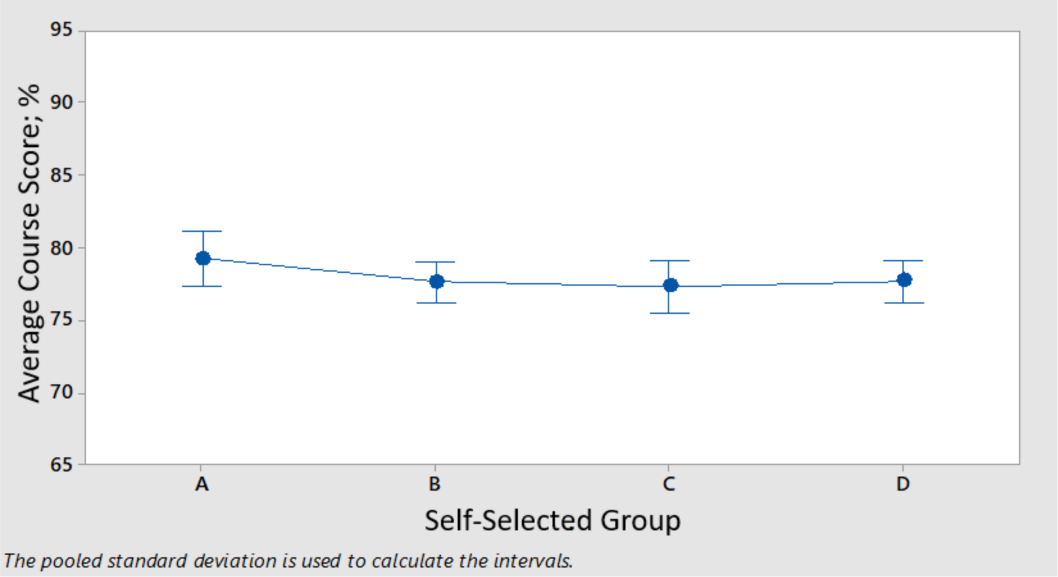
Tukey interval plot of average final course scores for self-selected groups, 2014; ANOVA output: F(3, 769) = 2.47, $p < 0.061$



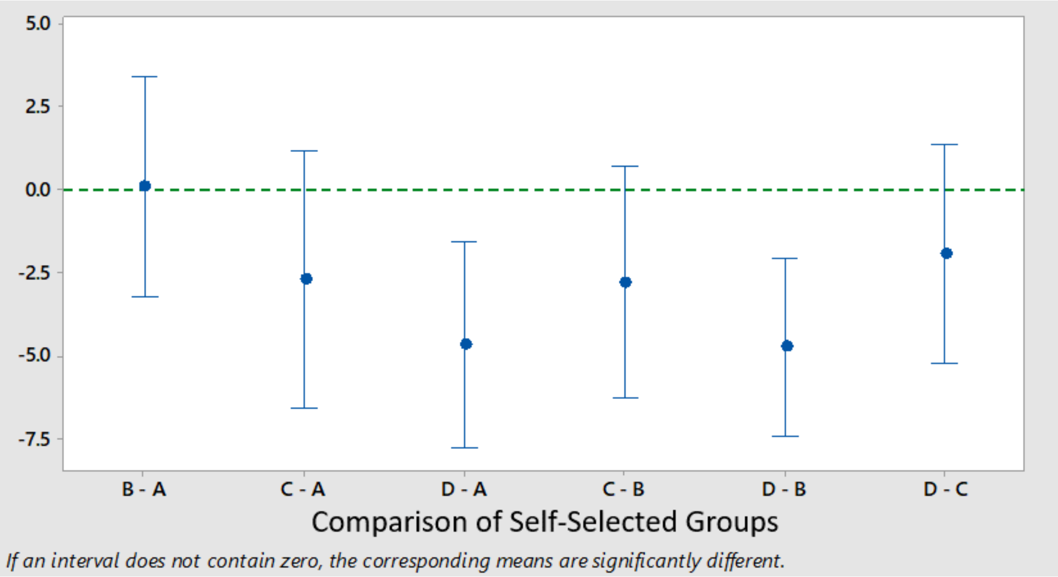
Average fall semester final course scores by self-selected group, 2014



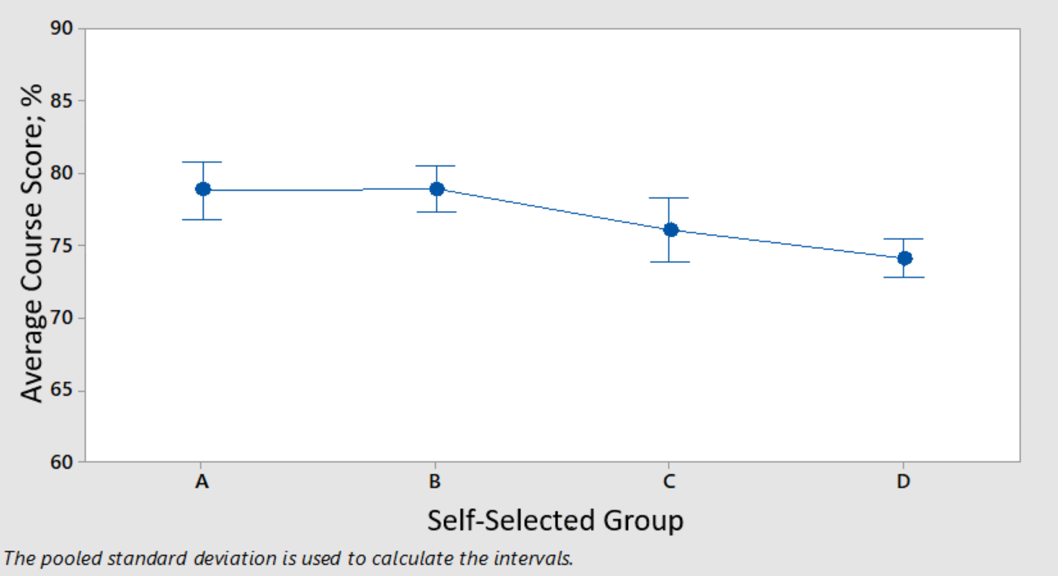
Tukey interval plot of average final course scores for self-selected groups, 2015;
ANOVA output: F(3, 851) = 0.84, $p < 0.473$



Average fall semester final course score by self-selected group, 2015



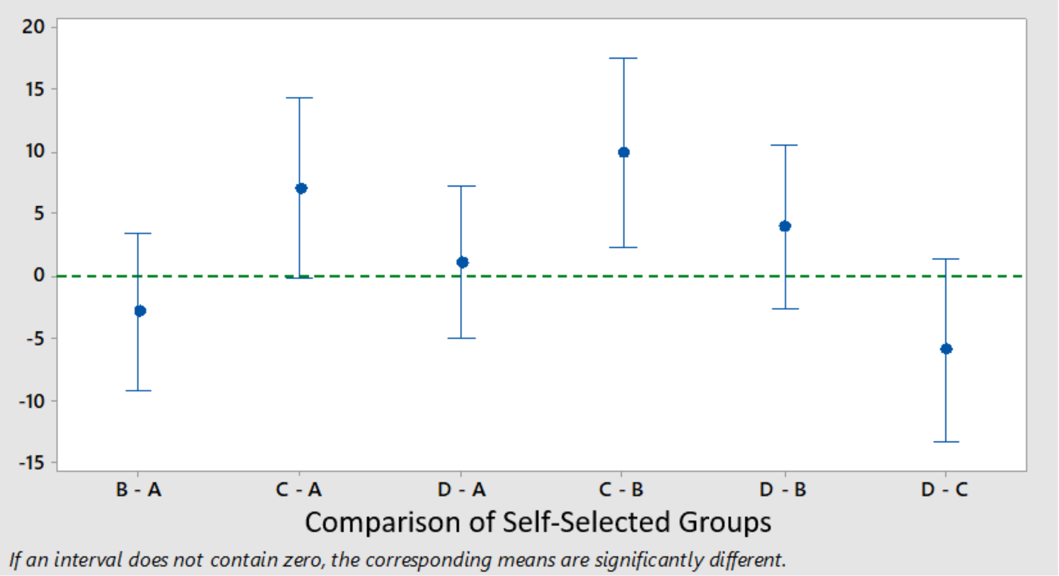
Tukey interval plot of average final course scores for self-selected groups, 2016; ANOVA output: F(3, 802) = 8.95, $p < 0.001$



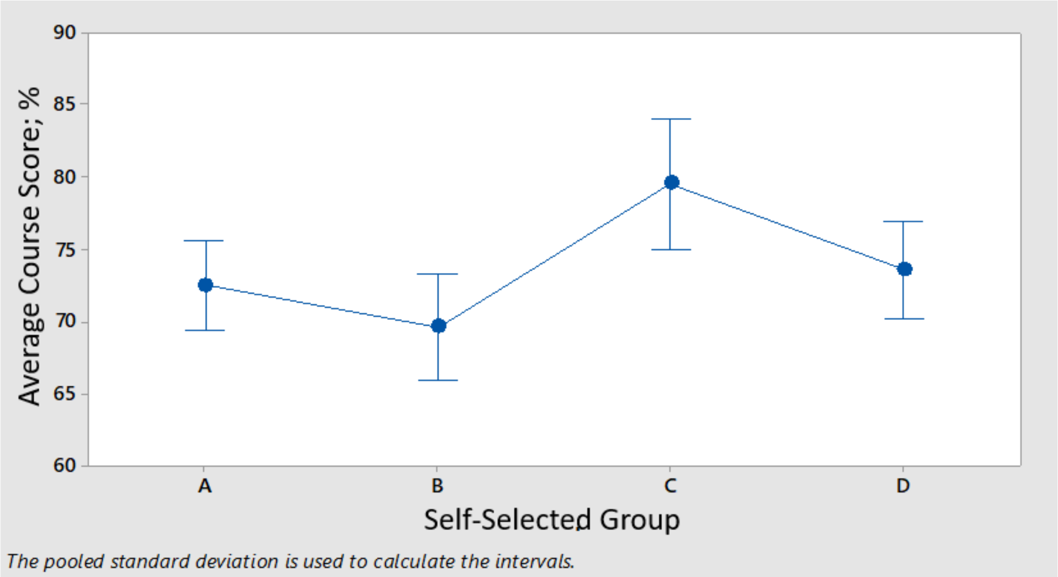
Average fall semester final course scores by self-selected group, 2016

APPENDIX L

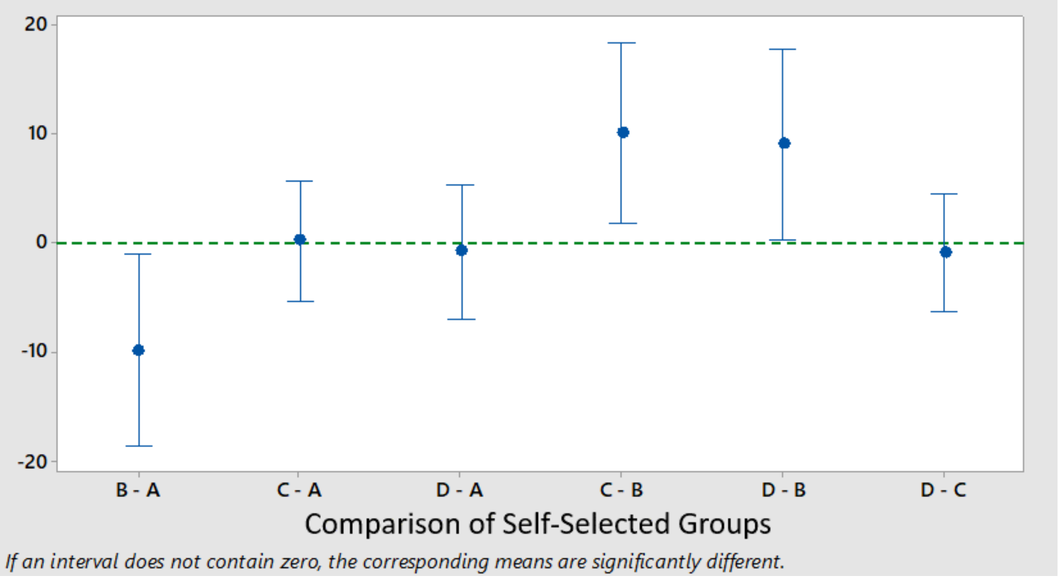
SPRING SEMESTER OVERALL PERFORMANCE DATA, 2013 – 2017



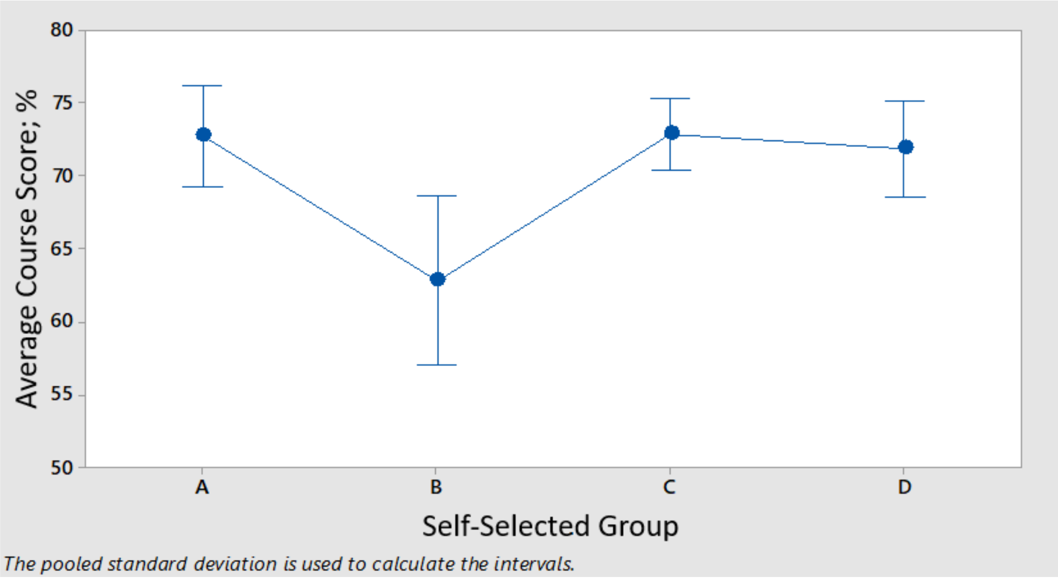
Tukey interval plot of average final course scores for self-selected groups, 2013; ANOVA output: F(3, 175) = 3.90, $p < 0.011$



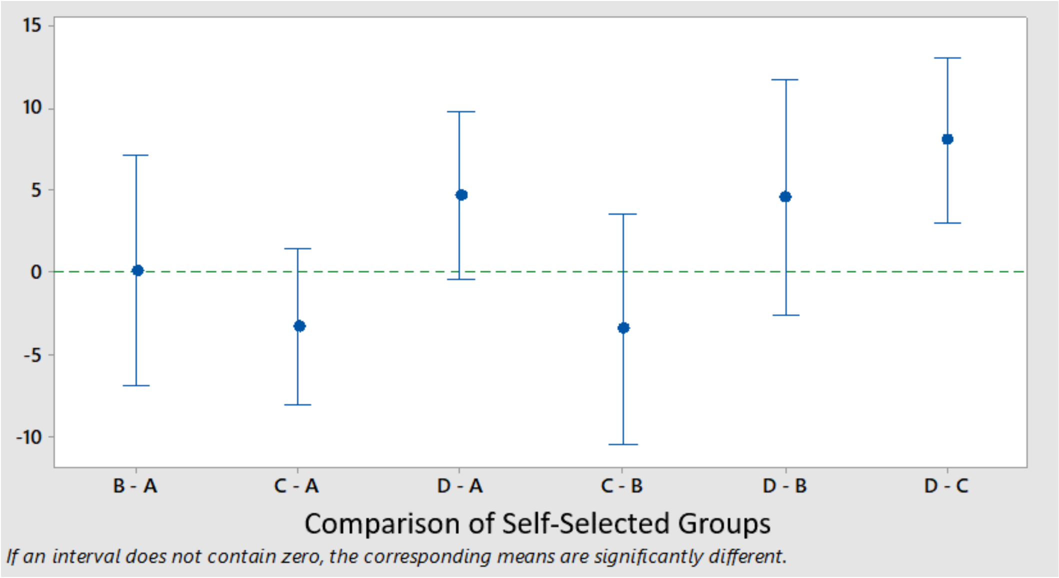
Average spring semester final course scores by self-selected group, 2013



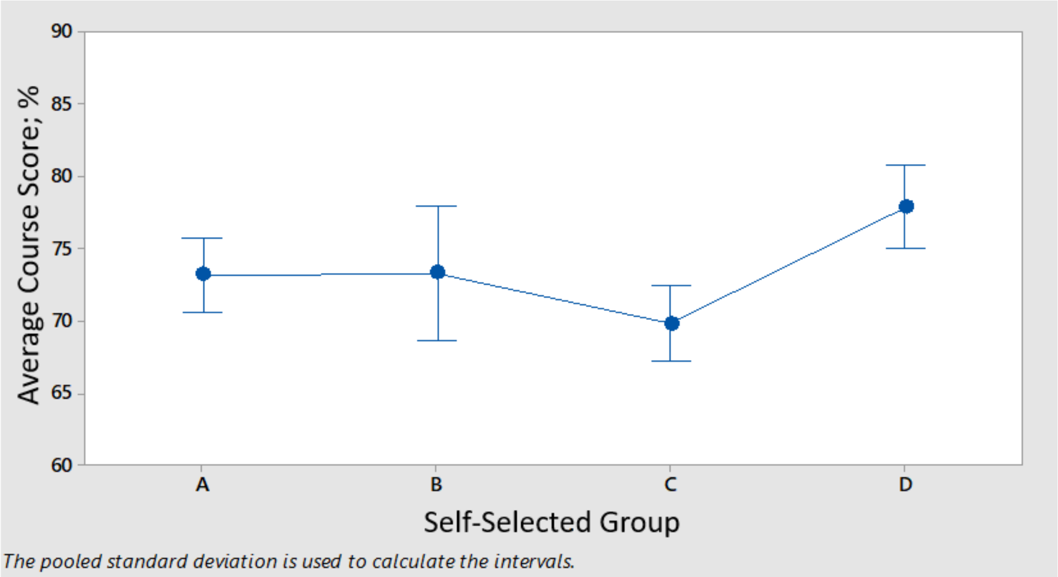
Tukey interval plot of average final course scores for self-selected groups, 2014;
ANOVA output: F(3, 227) = 3.44, $p < 0.019$



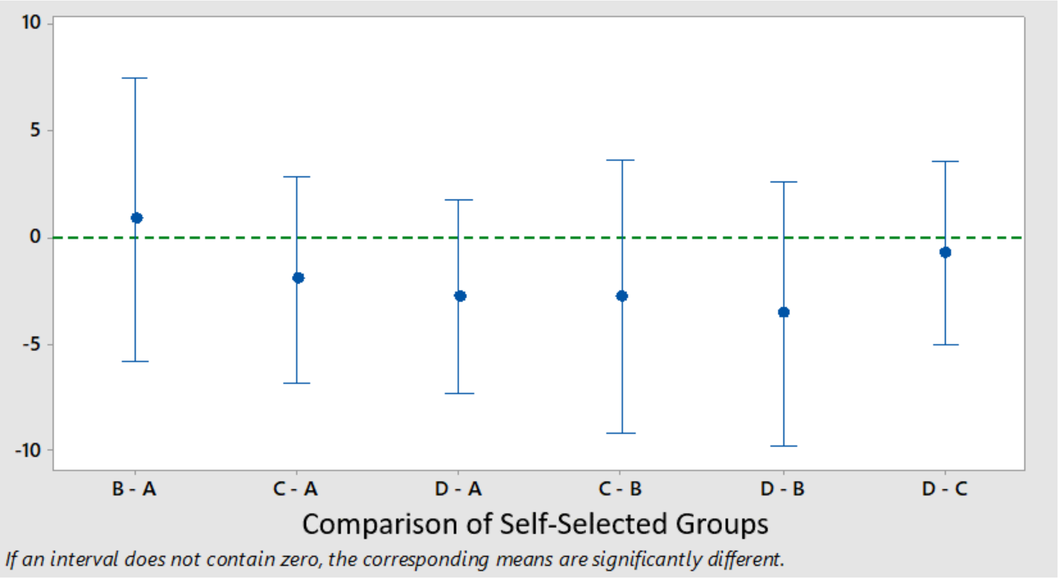
Average spring semester final course scores by self-selected group, 2014



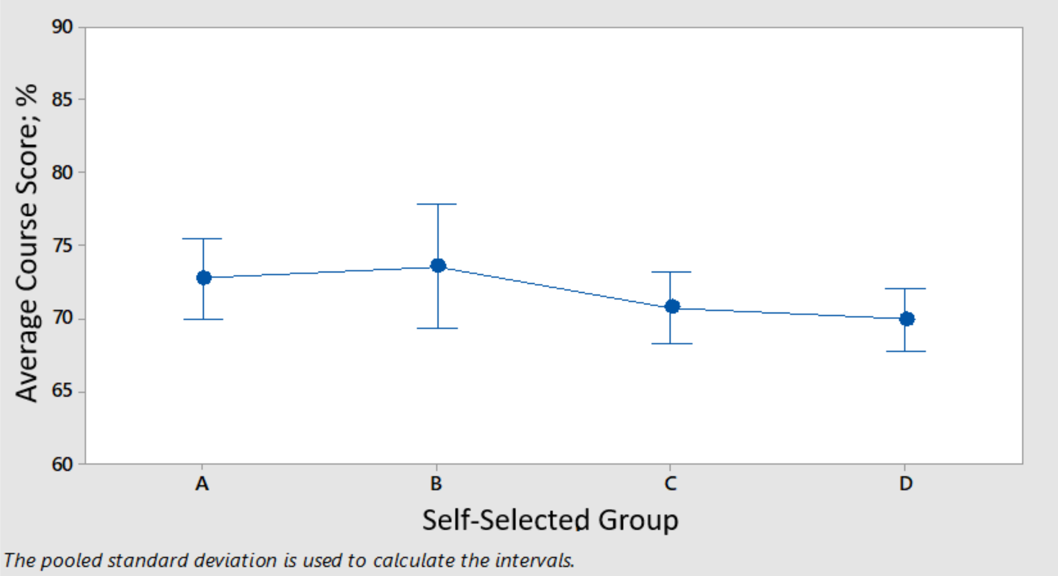
Tukey interval plot of average final course scores for self-selected groups, 2015; ANOVA output: $F(3, 193) = 5.72, p < 0.002$



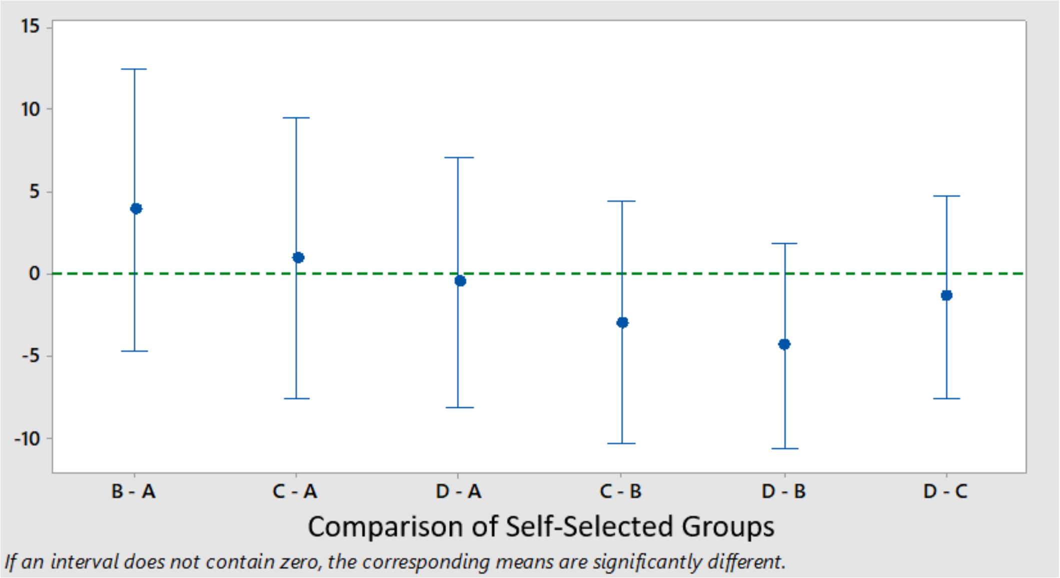
Average spring semester final course scores by self-selected group, 2015



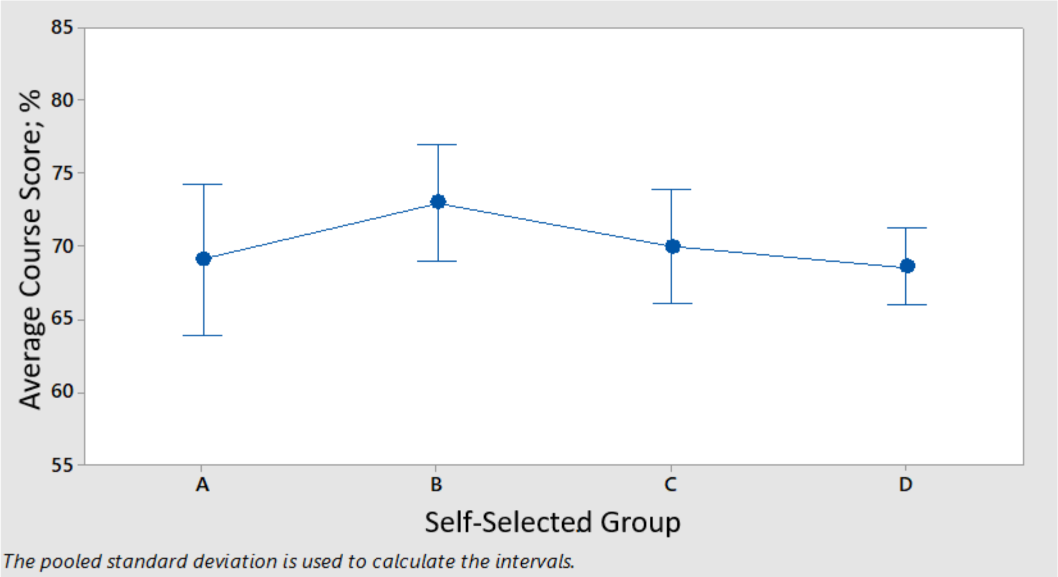
Tukey interval plot of average final course scores for self-selected groups, 2016; ANOVA output: $F(3, 235) = 1.31$, $p < 0.274$



Average spring semester final course scores by self-selected group, 2016



Tukey interval plot of average final course scores for self-selected groups, 2017; ANOVA output: F(3, 251) = 1.12, $p < 0.344$



Average spring semester final course scores by self-selected group, 2017

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VITA

Travis Rae McDowell earned an Associates in the Arts with an emphasis in Chemistry in 2004 from Mineral Area College in Park Hills, MO. He transferred to Missouri University of Science and Technology (formerly the University of Missouri-Rolla) where in 2006 he earned a Bachelor's of Science in Chemistry. In May 2018 he received his PhD in Chemistry from Missouri University of Science and Technology.

During his time at Missouri University of Science and Technology, Travis participated in the development and implementation of a redesign for the first-year general chemistry courses. As part of his participation he also worked on multiple grants used to further the redesign mission and acted briefly as a coordinator for the course. Additionally he worked to train the many undergraduate and graduate assistants in the methods employed so that they could be more effective with maintaining the goals of the redesign. He has also worked to disseminate the achievements and pitfalls of the redesign through peer-reviewed research and presentations. Beyond his work to help redesign the first-semester general chemistry course he also assisted with further redesigns of the second-semester general chemistry course in addition to the general chemistry lab course.