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Course-Integrated Undergraduate Research Experiences Structured at Different Levels of Inquiry

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Abstract

Enhancing undergraduate students' preparation and interest in science careers frequently involves engagement in authentic research experiences. Traditional undergraduate research (UR) one-to-one faculty-to-student ratio is challenged by demand and cost, motivating the development of alternative approaches to offering these experiences. Embracing this challenge, we integrated UR experiences into three undergraduate biology courses, each taking a different approach to engaging students. The approaches varied the amount of teacher and student responsibility, reflecting different levels of inquiry instruction: one in which students were embedded into the faculty's on-going research; a second in which faculty provided the hypotheses and methodology and students were responsible for experiment details and implementation; and a third in which students were responsible for all aspects of research on any topic that fit within the scope of the course. We assessed and compared students' affective and cognitive outcomes related to engagement in scientific research. Overall, all participants felt their experiences were effective for learning and positively influenced interest in and knowledge of science. However, students' perceived gains differed, with greatest gains detected in students engaged in the most authentic inquiry approach (ANOVA: $p < 0.01$).

1. Introduction

The typical undergraduate science curriculum is designed to provide students with opportunities to gain knowledge of both the content and process of science (Sunal, Wright & Day, 2004). While content is presented in lecture, the procedural knowledge of science is typically taught through lab courses, where undergraduate students engage in investigations. Yet these experiences frequently do not provide students with an authentic understanding and accurate perspective of scientific research (Buck, Bretz, & Towns, 2008; Chinn & Malhotra, 2002). Opportunities for more authentic exposure to scientific research are more likely to occur when undergraduate students engage with faculty in one-to-one undergraduate research (UR) experiences. The successes of UR experiences (Kardash, 2000; Lopatto, 2003; Seymour, Hunter, Laursen, & DeAntoni, 2004), provide justification for exploring additional approaches which could expand opportunities for more students to gain exposure to and experience with scientific research.

One possible approach is to integrate scientific research experiences into the course curricula (Trosset, Lopatto, & Elgin, 2008). The potential for course-integrated research to engage all enrolled students in a UR experience effectively addresses the call to increase the number of students involved in UR experiences (Hunter, Laursen, & Seymour, 2008; Taraban & Blanton, 2008). In addition, course-integrated UR experiences provide students more chances to collaborate on and support each other in conducting research, which increases the potential for establishing career-long relationships (Taraban & Blanton, 2008). Yet there is limited research exploring course-integrated research to determine how best to structure these experiences to maximize benefits to undergraduate science students. In this study, we address this gap in the literature by comparing three different course-integrated research experiences and evaluating the students' affective and cognitive responses to their experiences.

We begin our investigation report with an exploration of literature reviewing research investigating UR experiences. We propose classifying course-integrated UR experiences based on the levels of inquiry (Schwab, 1962). We then discuss these levels of inquiry and provide justification for using this system to examine and compare various forms of course-integrated UR experience. This discussion is followed by a presentation of our research questions, hypotheses, and discussion of our methodology. We then present our analysis, scrutinizing our data both collectively and by course. We conclude with a discussion of the outcomes, limitations of our study, and implications.

2. Undergraduate Research Experiences

Undergraduate research (UR) experiences have been used as a process for increasing undergraduate student knowledge of scientific methods and content and as a vehicle for increasing their interest in careers in science (Kardash, 2000; Lopatto, 2004; Seymour, Hunter, Laursen, & DeAntoni, 2004). Through UR experiences, students engage in situations in which they can gain experience with scientific research and increase their understanding of science knowledge while being formally introduced to science research as a profession (Hunter, Laursen, & Seymour, 2006).

Undergraduate research has been traditionally typified by pairing a student with a faculty researcher for a one-to-one research experience (Lopatto, 2004). Customarily, the undergraduate student becomes involved in the research of the sponsoring faculty as a member of the research team working on the sponsor's research agenda, but there may be variations in the structure in which students offer their own unique directions or ideas for investigations (Hakim, 1998: Kardash, 2000; Millspaugh & Millenbah, 2004). In addition, students participating in UR may take over responsibility for conducting some aspect of the on-going research, including reporting results at professional conferences and drafting manuscripts for publication (Burnley, Evans, & Jarrett, 2002).

Investigations of UR experiences report a range of beneficial outcomes for students involved in UR (Lopatto, 2003; Russell, Hancock, & McCullough, 2007; Seymour, Hunter, Laursen, & DeAntoni, 2004). Studies investigating UR experiences report increases in participants' interest and knowledge of scientific research and motivation to pursue scientific careers (Lopatto, 2007). However, it is widely recognized that many students engaging in UR are already motivated to become involved in these activities and are predisposed to interest in science careers (Lopatto, 2007).

Benefits for faculty sponsoring UR experiences include satisfaction with working with undergraduates (Russell, 2008), increases in lab productivity, and the recruiting of students for longer-term projects and into the field. In addition, new perspectives of research may result from student involvement in UR leading to new or more productive directions for research (Bauer & Bennett, 2008).

Growing student awareness of the benefits of the UR experience has intensified demand for these opportunities (Merkel, 2003). Yet there are limitations to the resources available to offer and sustain the traditional one-to-one student to faculty ratio approaches to UR experiences (Blanton, 2008; National Science Foundation [NSF], 2004; Russell, 2003). The combination of undergraduate enrollment growth at many institutions (Livingston, 2008), increased internal and external competition for funding to support undergraduate research (Bauer & Bennett, 2008; Monastersky, 2007: Russell, 2003), and increased student desire to engage in UR (Merkel, 2003) may overwhelm the traditional UR pairing of one student to one faculty researcher (Hunter, 2007).

Yet student and faculty benefits of UR experiences provide motivation for seeking new options that support UR engagement. One possible solution is to integrate UR experiences into undergraduate science courses. In their study examining course-integrated research experiences, Trosset, Lopatto, and Elgin (2008) report student benefits equivalent to full-time research experiences. In their investigation, Trosset and colleagues explored the benefits of full-time UR experiences to course-integrated experiences, but did not compare outcomes between courses. This suggests that there is justification for exploring outcomes from course-integrated UR experiences to determine the structure that leads to the highest levels of student benefit.

For optimal outcomes, research experiences should maximize student learning as they engage in authentic scientific research experiences. The implemented structures of course-integrated UR may vary widely, which influence the depth to which the participating students engage in scientific inquiry. However, as Settlage (2007) argues, many students may not be prepared to engage in the level of inquiry associated with authentic professional research and, therefore, students often require additional guidance and support to maximize the benefits. This begs the question: how does the level of inquiry of course-integrated UR experiences relate to the benefits of student engagement? To investigate this relationship, we used Schwab's (1962) levels of inquiry model to provide a rationale for classifying and investigating the structure of course-integrated UR experiences.

3. Levels of Inquiry

The definition of *inquiry* continues to be debated and refined (Buck, Bretz, & Towns, 2008; Chinn & Malhotra, 2002; Martin-Hansen, 2002; NRC, 1996, 2000). From a pragmatic perspective, a scientific inquiry should have the detectable presence and implementation of three essential elements: research question(s), methodology and data collection, and interpretation and explanation of results (Schwab, 1962; Herron, 1971). Using the model proposed by Schwab (1962), student and teacher roles in an inquiry can generally be classified into four levels. This four-tiered classification scheme is based on the level of teacher and student responsibility for the three essential inquiry elements. The level of inquiry increases from 0 to 3 as the responsibility for the investigation shifts from teacher to learner (see Figure 1). At Level 0, the teacher provides the questions, methodology for gathering data, and interpretation of the data. By Level 3, the learner is working mostly independently assuming responsibility for all three inquiry elements. Using Schwab's classification scheme we were able to identify and classify our three course-integrated research experiences according to the levels of inquiry. Further, this scheme allowed us to consistently use the inquiry concept while attending to the differences in the inquiry structure of course-integrated research experiences.

There are challenges and benefits to engaging students in research at each of these levels of inquiry (Kinkead, 2003). There are no specific criteria for which level of inquiry is most effective for learning because different structures can be effective for meeting different needs. Students' knowledge and abilities are

Inquiry Level	Source of the Question	Data Collection Methods	Interpretation of Results
Level 0	*Given by teacher*	*Given by teacher*	*Given by teacher*
Level 1	*Given by teacher*	*Given by teacher*	***Open to learner***
Level 2	*Given by teacher*	***Open to learner***	***Open to learner***
Level 3	***Open to learner***	***Open to learner***	***Open to learner***

Figure 1. Schwab's levels of inquiry (Schwab, 1962).

good criteria for setting the appropriate level of inquiry to use to guide the structure of research activities that maximize meaningful involvement and success with learning (Buck, Bretz, & Towns, 2008; Chinn & Malhotra, 2002; Duschl & Grandy, 2008). For example, if students lack research experience or possess constrained views of the scientific method, they require more structure and support and less independence to effectively conduct research (Chinn & Malhotra, 2002; Settlage, 2007). A Level 0 or 1 inquiry structure might be most appropriate for these students. The Level 0-1 structure may include scaffolding and other forms of support to guide students through the process of forming reasonable testable research questions, and then developing appropriate methodology for conducting the research.

The situation is different for students who have experience and confidence with scientific research and have demonstrated some level of expertise by previously conducting an independent scientific study (Chinn & Malhotra, 2002; Settlage, 2007). Although rare, these students may be prepared to engage in investigations at nearly the same level as expert scientific researchers (Settlage, 2007). Experienced students may be prepared and willing to assume the responsibility and levels of independence necessary to successfully complete all aspects of a scientific investigation. Learners with this level of experience may be able to effectively engage in course-integrated UR experiences that have a Level 2 or 3 inquiry structure.

Regardless of the level of inquiry or the structure of the experience, the goal of UR is to provide students with exposure to the authentic practices and activities of professional scientists (Lopatto, 2003, 2007; Taraban & Blanton, 2008). As a component of undergraduate coursework, scientific lab activities are intended to provide students with exposure and experience related to the process of doing science, but at the same time these experiences may limit their understanding of scientific research (Buck, Bretz, & Towns, 2008; Duschl & Grandy, 2008; Glasson & McKenzie, 1998). Authentic science involves the ability to engage in creative thought, exercise problem solving abilities, assert multidisciplinary perspectives, and maintain knowledge of the literature (Duschl & Grandy, 2008; Hogan & Maglienti, 2001; Kuhn, Amsel, & O'Loughlin, 1988; Kuhn & Pearsall, 2000; Schunn & Anderson, 1999). The motivation to provide students with exposure to and experience with all these aspects of science justifies offering students opportunities to engage in authentic scientific inquiry. The final determination of the level of inquiry that is most appropriate for course-integrated UR experiences should be based on the anticipated experiences and knowledge of the students (Bauer & Bennett, 2008; Settlage, 2007). The goal of this research project was to explore these relationships.

4. Predictions and Hypotheses

In an effort to expand understanding of the influence of the structure of UR experiences on student learning, we investigated three different approaches to course based UR, classified by levels of inquiry. We sought to determine the influence of the course experiences on the cognitive (learning content) and affective (feeling and attitudes) outcomes of students engaged in science research structured at three different levels of scientific inquiry.

We predicted that there would not be detectable differences in the affective measures between courses. We hypothesized that all students would view the engagement in some level of scientific research as worthwhile, motivational, and rewarding, and therefore, would voice equal levels of appreciation for their experience with no effect due to subject matter knowledge, years of college, or the level of inquiry structure of their course-integrated research experience. We additionally predicted that students who engaged in UR experiences with a higher level of inquiry structure would communicate a greater understanding of scientific research and the processes by which science operates. We hypothesized that increased levels of student independence and responsibility for research would provide them with increased opportunity to learn about the processes of science, and therefore, consistent with the reports in Taraban and Blanton (2008), would lead to increased engagement in research resulting in increased understanding of scientific research.

4.1 Research Questions

The research questions guiding this investigation were:

1) Do undergraduate students involved in different levels of course-integrated scientific inquiry differ in measures of affective outcomes?
2) Do undergraduate students involved in different levels of course-integrated scientific inquiry differ in cognitive assessments of their understanding of scientific research?
3) What were the communicated perceptions of the undergraduates engaging in course-integrated research experience?

5. Methodology

5.1 Participants

This project took place in a large urban university located in the southeastern United States. The overall demographics of the participants were: 23.2 years of age (SD = 3.54): 27% male and 73% female: 87% Caucasian, 6% multiracial, and 7% all other ethnic groups. The sample was composed of 91% Biology majors, with 51% intending to go to professional or graduate school in a biology related field. Of the 55 participants, 56% had never engaged in a prior UR experience.

The participants from the three courses did not differ in age, major or number of college-level biology courses. The participants in the three courses did differ on their engagement in previous UR experiences, $\chi2$ (2) = 11.27, $p < .01$. Additional analysis revealed that Course A had significantly lower proportion of participants with prior research experience than Course B $\chi2(1) = 11.27$, $p < .01$, and Course C $\chi2$ (1) = 4.46, $p < .05$. Therefore, it is important to consider our research outcomes in the context of differential levels of prior experience between the participants in Course A when compared to the Course B and Course C students.

The 55 participating undergraduate students were recruited from three biology courses that integrated a research experience structured at different levels of inquiry as part of the curriculum. The courses involved in this study were spread over fall, spring and summer semesters. Due to departmental scheduling constraints, it was not possible to run all courses during a single semester simultaneously forcing students to choose only one of the three course options, and we acknowledge that this impacts the robustness of our statistical design. It also allowed there to be a limited number of students that overlapped between two or three of the courses (n < 5). However, because we agreed to ensure anonymity of all participants we were unable to identify the students who overlapped between courses and examine their outcomes independently.

5.2 Courses, Research Experiences, and Levels of Inquiry

Course A:Animal Behavior. This upper-division elective focused on the evolution of behavior. This course, offered in the fall semester, involved students in a Level 0 inquiry research experience with the faculty providing the research question and the methodology, and the students were responsible for gathering data, but not analyzing results. Students assisted with data collection independently and received help from the instructor or teaching assistant as needed. At the end of the semester, the course teaching assistant presented the class with

Sample	n	Age	Gender	Yrs until Grad	Prior Research
		M (SD)	(M/F)	*M (SD)*	(Yes/No)
Course A	**17**	**23.53 (4.46)**	**6/11**	**2.12 (.78)**	**2/15**
Course B	**25**	**23.36 (2.86)**	**5/20**	**2.32 (.56)**	**16/9**
Course C	**13**	**22.46 (3.57)**	**4/9**	**3.08 (.95)**	**6/7**
Total	**55**	**23.20 (3.54)**	**15/40**	**2.44 (.81)**	**24/31**

Table 1. Participant Demographic

a summary of data collected during the term. A Level 0 inquiry research experience was selected for this course because the enrolled students typically had very limited authentic scientific research experience. In addition, these undergraduate students were returning from summer break and most likely had not established a habit for scientific thinking and were anticipated to be in need of additional support to reestablish a scientific frame of mind. Final determination of a Level 0 inquiry in the course was supported by the faculty member's desire to integrate the students into an existing research agenda, which had established research questions and methodologies. About 5% of students' final course learning assessment was attributed to their performance on their UR projects. Approximately 10% of the students exceeded the instructor's expectations and continued to seek additional UR opportunities.

Course B: Marine Biology. This upper-division elective focused on ecology and biodiversity in marine ecosystems. This course (Course B) was offered in the spring and engaged students in a Level 2 inquiry. The faculty member provided the research questions and directions for investigation and then gave the students the responsibility to propose, develop, and implement a methodology for gathering data and conducting an analysis of the results. The students worked in groups of up to 6 individuals and each group had an unpaid graduate student as a mentor. One of the goals of Course B was the creation of a scientific poster presentation with the expectation that students present their findings at the university's annual undergraduate research showcase. The choice of the Level 2 inquiry structure of this course-integrated research experience was made based on the faculty's desire to achieve the poster presentation goal while providing the students with an opportunity to explore unique avenues within the confines of the faculty's established research agenda. Also, since this course was offered in the spring there was an expectation that students had developed or regained abilities to think scientifically, and therefore, could work more independently and did not require the same level of support as the students entering the fall course. About 18% of the assessment of student learning was based on their UR project. Following the completion of the course over 50% of these students continued working on UR projects and presented their results at regional meetings or published their results at the university's online undergraduate research journal.

Course C: Tropical Marine Biology. This upper-division, elective, study-abroad course focused on coral reef ecology, biodiversity and research. This third course was offered the first week of summer semester (Course C) and focused almost exclusively on research. This course involved traveling abroad to conduct biological field research at a marine laboratory in Central America. The structure and curriculum of the course heavily emphasized conducting scientific investigations in the field, integrating these activities as a major activity in the course. There was an expectation that all students would orally present their research to their peers in the course. After spending the first half of the course examining biodiversity and ecology, students used this information to brainstorm potential research ideas as a group. Students then individually picked their research topic, creating groups of 3-4 people. Since students were responsible for the development and implementation of all aspects of a scientific investigation, they were engaged in research at Level 3 inquiry. The choice for integrating Level 3 inquiry in this course was made by the faculty to provide the enrolled students an opportunity to explore topics of personal interest and conduct authentic scientific research on these topics in the field. Approximately 40% of the students' learning assessment was based on their performance on their UR projects. All students in the course met the expectations of the instructor.

Measures

Shortly after the students had completed their courses they were asked to complete our UR experience survey. The survey used in this investigation was a compilation and modification of two extant instruments, the Survey of Undergraduate Research Experience (SURE) and the Classroom Undergraduate Research Experience (CURE), both developed by Lopatto (2004, 2008). Modification was needed to align the items on the instrument with the structure of our course-integrated UR experiences. We modified the surveys to focus on affective measures (attitudes and feelings) of course-integrated scientific research as well as cognitive (learning content) measures of understanding of the science and scientific research process. Extraneous questions regarding mentors, collaboration with more experienced students, and other items on the SURE and CURE not associated with our course-integrated structure were not included on our modified instrument. Our final instrument contained 62 forced response

Likert scale items and 1 open response item, forming 4 subscales; motivation for enrolling in the course, perceived benefits of the course, perceived gains from the course, and overall impression. The survey provided a context such as, *"Benefits to your involvement in research"* and requested participants to respond on a Likert scale to affective items such as *"Tolerance for obstacles faced in the research process"* and cognitive items such as *"Understanding of the research process in your field."* A Cronbach's alpha analysis of the internal reliability of our modified instrument was revealed to be .90, indicating a high level of instrument stability (Crocker & Algina, 1991).

A total of 75 questions were used to assess demographics, prior scientific research experience, attitudes and feelings (affective measures) about the course-integrated UR experience, and perceived knowledge (cognitive measures) gained from the experience. The research experience survey questions were Likert-scale formatted, with the exception of the final question, which allowed participants to openly express their general overall perceptions of their UR experiences in narrative form. The questions were delivered through the Internet using the Zoomerang web-based survey software (See http://www.zoomerang.com). One of the parameters provided by Zoomerang to survey designers is a "Question is Mandatory" option. We selected this option for all 75 items to assure all surveys were complete and did not contain missing responses.

The data collection took place during the spring and early summer semesters. At the beginning of spring semester we used the course roster from Course A to e-mail the enrolled students with a request for them to participate in the study and complete the survey. Of the 48 students who completed Course A the prior semester, 17 responded and completed our survey. The students in Courses B and C were asked in class to participate and complete the survey at the end of the course. All of the students from these two courses participated, for a total of 25 for Course B and 13 for Course C. It is important to note that a considerably lower proportion of students from Course A responded when compared to the percentage of the enrolled students who responded in the other two courses and there may have been a bias toward positive responses. Further, there was a longer delay between completion of the UR experience and post-experience data collection of the Course A students. Therefore, our results must be considered within this context.

6. Results

6.1 Quantitative Data

We used composite data, produced by grouping responses from all three courses, to examine subgroups of items from our instrument that were representative of affective perspectives of research or cognitive aspects of scientific research. We calculated the means and standard deviations for each item within our subgroups for further analysis, and we focused our results on survey items that were revealed to represent either high or low extremes in student responses because we sought to expose trends. Therefore, we did not explore the outcome for each of the 75 items, but restricted our reporting to those key items from our subgroup that had the highest and lowest means. We then examined the individual items using ANOVA to determine if there were significantly different responses to the items between the three courses. For continuity, we present the two items from the survey that we did not include in our analysis as figures in the Appendix.

We conducted all of our analyses at a significance level of .05. Convention suggests this method of analysis necessitates error correction to compensate for the possibility of Type I errors. However, Rossi, Lipsey, and, Freeman, (2004) provide justification for maintaining a higher level of significant (alpha = .05) with smaller sample sizes, to compensate for the reduced power and the increased probability of type II error.

6.1.1 Motivation for Course Enrollment.

Our analysis began with an examination of the means of a group of 10 items measuring participant motivation for enrolling in the course. The means and standard deviations for these items in the order that they appeared on the survey are presented below in Table 2. These items were rated on a three-point Likert scale, with "1" representing "Not Important" extending to "3" representing "Very Important." Because these items were related to motivation, we considered these to be measures of affective outcomes. The participant responses indicated that interest in the subject matter was the most important influence on decision to enroll in the courses (M = 2.87, SD = .39) which was followed by a desire to learn more about scientific research (M = 2.44 SD = .66). The least important contributing factors were fulfillment of a distribution requirement (M = 1.36 SD = .85), and meeting graduate school entrance require-

Question Content	Course A	Course B	Course C	Total
	M(SD)	M(SD)	M(SD)	M(SD)
Fill a distribution requirement	1.35(.79)	1.52(.92)	1.08(.76)	1.36(.85)
Fill a requirement for my major	2.12(.78)	2.32(.80)	1.62(1.04)	2.09(.89)
Needed for graduate or professional school	1.53(.87)	1.4(.87)	1.15(1.07)	1.38(.91)
Needed for my desired employment after college	1.76(.75)	2.32(.99)	1.92(.86)	2.05(.91)
Interest in the subject matter	2.88(.49)	2.84(.37)	2.92(.28)	2.87(.39)
To learn lab techniques	1.47(.87)	2.00(.87)	1.77(1.01)	1.78(.92)
To learn about science and the research process **	2.00(.71)	2.56(.58)	2.77(.44)	2.44(.66)
To get hands-on research experience **	2.00(.71)	2.32(.85)	2.85(.38)	2.35(.78)
It fit in my schedule *	1.59(.80)	2.12(.93)	1.38(.96)	1.78(.94)
The course and/or the instructor has a good reputation	2.35(.70)	2.28(.89)	2.46(.78)	2.35(.80)

ANOVA * $p < .05$, ** $p < .01$

Table 2. The Means and Standard Deviations of the Measures of Motivation for Enrolling

ment (*M* = 1.38 *SD* = .91). This suggests that as a group the students were initially motivated to enroll in the courses by a desire to learn more about the corresponding course content.

Using the enrolled course as the grouping factor we conducted an ANOVA of the 10 items listed in Table 2 as the dependent variables. The results revealed three items measuring course motivation in which the courses differed significantly. A significant difference was found for participant rating of the importance for learning more about science $F(2,52) = 7.12$, $p < .01$, with post hoc analysis revealing that Course A rated the importance significantly lower than the other two courses ($p < .01$). A significant difference was found for the importance of getting hands-on experience $F(2,52) = 5.08$, $p < .01$, with post hoc analysis revealing Course C reporting a higher level of importance than Course A ($p < .01$). Finally, there was a significant difference measured for the importance of fitting a course into a schedule $F(2,52) = 3.45$, $p < .05$. Post hoc analysis revealed that this was a more important consideration for Course B than for those enrolled in course C ($p < .05$).

In appears there was greater motivation to learn subject matter and experience hands-on activities for the students enrolling in Course C and a significantly lower emphasis on fitting a course into a schedule. This suggests that motivation for enrolling was different between courses which may be explained by the fact that Course C was a study-abroad, summer semester course and required a different level of student commitment.

6.1.2 Cognitive and Affective Gains.

Our analysis continued with an examination of the mean scores of items measuring perceived gains due to involvement in the UR experience. Twenty items measured both affective and cognitive benefits from their involvement in UR and were rated on a five point Likert scale, ranging from 1 (“No Gain”) to 5 (“Very Large Gain”) (see Table 3). The four items with the highest mean scores for gain measured understanding of how scientists work on real problems (*M* = 4.31, *SD* = .92), understanding of the research process in your field (*M* = 4.02, *SD* = 1.01), ability to analyze data and other information (*M* = 3.84, *SD* = 1.05), and ability to integrate theory and practice (*M* = 3.84, *SD* = 1.03).

The four items with the lowest mean score (indicating lowest gains in learning) were: learning to work independently (*M* = 2.45, *SD* = 1.02), skill in how to give an effective oral presentation (*M* = 2.76, *SD* = 1.41), ability to read and understand primary literature (*M* = 2.80, *SD* = 1.32), and skill in science writing (*M* = 2.91, *SD* = 1.28) (see Table 3).

Items with the highest mean scores were both cognitive (items associated with learning content) and affective (items associated with feelings about involvement in the process), indicating that students experienced large gains in both areas. However, the lowest scoring items were associated exclusively with the processes and procedures of science and did not include affective measures. This suggests that gains in learning and understanding more about science were less than accompanying gains in appreciation for science.

An ANOVA on the 20 items assessing experience benefits among courses revealed significant differences for eight items. Differences were found for several items related to the presentation of results (see Table 3). Significant differences in perceived measured gains were

Question Content	Course A	Course B	Course C	Total
	M(SD)	M(SD)	M(SD)	M(SD)
Clarification of career path **	**2.59(1.11)**	**3.60(1.19)**	**3.77(1.09)**	**3.33(1.23)**
Skill in the interpretation of results *	**2.76(1.25)**	**3.60(1.00)**	**3.77(.83)**	**3.38(1.11)**
Tolerance for obstacles faced in the research process	**3.12(1.36)**	**3.88(.97)**	**3.69(1.03)**	**3.60(1.15)**
Readiness for more demanding research*	**2.76(1.56)**	**3.64(1.08)**	**4.00(1.08)**	**3.45(1.32)**
Understanding how knowledge is constructed	**3.35(1.17)**	**3.60(1.32)**	**4.08(.76)**	**3.64(1.18)**
Understanding of the research process in your field	**3.82(1.13)**	**4.12(1.09)**	**4.08(1.12)**	**4.02(1.10)**
Ability to integrate theory and practice	**3.53(1.18)**	**3.88(.97)**	**4.15(.90)**	**3.84(1.03)**
Understanding of how scientists work on real problems	**4.12(.78)**	**4.40(1.08)**	**4.38(.77)**	**4.31(.92)**
Understanding that scientific assertions require supporting evidence *	**3.47(1.07)**	**3.92(1.19)**	**3.69(.75)**	**3.73(1.06)**
Ability to analyze data and other information	**3.71(1.05)**	**3.84(1.14)**	**4.00(.91)**	**3.84(1.05)**
Understanding science	**3.47(1.01)**	**3.76(1.33)**	**3.69(1.03)**	**3.65(1.16)**
Learning ethical conduct in your field	**3.00(1.22)**	**3.28(1.51)**	**3.31(1.18)**	**3.20(1.34)**
Learning laboratory techniques **	**2.71(1.05)**	**3.92(1.19)**	**2.85(1.34)**	**3.29(1.30)**
Ability to read and understand primary literature	**2.41(1.37)**	**3.08(1.35)**	**2.77(1.17)**	**2.80(1.32)**
Skill in how to give an effective oral presentation **	**1.53(1.12)**	**3.16(1.21)**	**3.62(1.04)**	**2.76(1.41)**
Skill in science writing **	**2.00(1.41)**	**3.40(1.12)**	**3.15(.69)**	**2.91(1.28)**
Self-confidence **	**2.12(1.17)**	**3.00(1.26)**	**4.00(1.15)**	**2.96(1.37)**
Learning to work independently	**2.29(1.31)**	**2.36(1.29)**	**2.85(.80)**	**2.45(1.20)**
Becoming part of a learning community	**3.12(1.17)**	**3.52(1.23)**	**4.08(.95)**	**3.53(1.18)**
Confidence in my potential to be a teacher of science *	**2.18(1.42)**	**3.00(1.38)**	**3.69(1.03)**	**2.91(1.42)**

ANOVA * $p < .05$, ** $p < .01$

Table 3. Means and Standard Deviations of Measures Associated with Measures of the Perceived Benefits

found for the interpreting results item $F(2,52) = 4.36$, $p < .05$, for the item assessing gains in oral presentation skills, $F(2,52) = 14.86$, $p < .01$, for the item measuring perceived gains in scientific writing, $F(2,52) = 8.01$, $p < .01$, and for the item measuring student understanding that scientific assertions require supporting evidence $F(2,52) = 4.94$, $p < .05$. The post hoc analysis showed that the students in Course B and Course C both reported significantly higher gains on these communication items than Course A ($p < .05$). Further examination of the ANOVA revealed a significant difference for perceived gains in readiness for more demanding research: $F(2,52) = 4.12$, $p < .05$. Post hoc analysis indicated the Course C students experienced a greater gain in readiness than their peers enrolled in Course A ($p < .05$). A significant difference was also found in perceived gains in laboratory techniques, $F(2,52) = 6.507$, $p < .01$; post hoc analysis indicated that Course B had higher measured gains than both Course A ($p < .01$) and Course C ($p < .05$). Two items that were found to be significant were both related to gains in confidence: the first was self confidence, $F(2,52) = 8.98$, $p < .01$, and the second assessed gains in confidence as a potential to be a science teacher, $F(2,52) = 4.93$, $p < .05$. Post hoc analysis of these items revealed that Course C perceived significantly higher gains than the participants in Course A ($p < .01$). These outcomes suggest that higher levels of responsibility and independence in research associated with experiences structured at higher levels of inquiry in Course B and Course C lead to greater perceived cognitive gains related to understanding and being able to communicate scientific research, and to increases in confidence in abilities.

6.1.3 Experiences that Lead to Learning. Our next analysis examined the means of the 23 items related to the perceived gains in learning in relationship to various course experiences (see Table 4). The items were rated on a five-point Likert scale, with numeric values ranging from "1" to "5" representing gains ranging from "No Gain" to "Very Large Gain." Items that assessed experiences in which participants communicated with each other exhibited the greatest gains in learning: data collection ($M = 4.09$, SD = 1.02), becoming responsible for part of project ($M = 3.91$, SD = 1.25), analyzing data ($M = 3.87$, SD = 1.06), and working in small groups ($M = 3.75$, SD = 1.14).

The experiences with the lowest gains in learning were associated with the following: working on a scripted lab in which the student already knows the outcome ($M = 1.89$, SD = 1.31), maintaining a lab notebook ($M = 1.84$, SD = 1.20), writing a research proposal ($M = 1.73$, SD = 1.73), and a working on a lab in which the instructor knows the outcome ($M = 1.60$, SD = .93). Students voiced positive gains in experiences that enhanced their independence as learners and researchers. It is interesting to note that experiences with the lowest gains are common exercises or events in the undergraduate curriculum in the sciences, yet the students did not view these activities as enhancing their learning.

Consistent with our prior analysis, we tested for differences among courses by ANOVAs on these 23 items. The results of the analysis revealed differences for 10 items (see Table 4). Three of these items, becoming responsible for part of a project, $F(2,52) = 4.86$, $p < .05$, working on a lab where no one knows the outcome, $F(2,52) = 9.05$, $p < .01$, and a project entirely of student design, $F(2,52) = 12.31$, $p < .01$, are all related to higher levels of independence associated with activities structured at higher levels of inquiry. The post hoc analysis of these items revealed that Course A communicated significantly lower gains from these experiences than their peers in the other two courses ($p < .05$). ANOVAs also revealed a trend in significant differences in gains from communication experiences, including maintaining a lab notebook, $F(2,52) = 11.30$, $p < .01$, presenting results orally, $F(2,52) = 17.79$, $p < .01$, and presenting results in a paper or a poster, $F(2,52) = 19.85$, $p < .01$. Post hoc analysis of these three items again revealed that Course A student has lower gains from these experiences than their peers that engaged in research experiences structured at higher levels of inquiry ($p < .01$). The post hoc analysis also indicated that the Course C students had significantly higher gains in learning from maintaining a notebook ($p < .01$), while Course B had indicated greater gains in learning from the experience of presenting results in a poster or paper than participants in the other two courses ($p < .01$). Courses B and C did not differ on the gains from presenting results orally.

Finally, our ANOVAs also revealed significant differences in gains in learning associated with more traditional learning activities. Significance was found for reading a textbook, $F(2,52) = 4.87$, $p < .05$, and for solving problems sets, $F(2,52) = 3.84$, $p < .05$, with our post hoc analysis revealing that Course A was significantly higher than Course B on these measures (p < 01). Our ANOVA analysis also revealed a

Question Content	Course A	Course B	Course C	Total
	M(SD)	M(SD)	M(SD)	M(SD)
Listen to lectures	3.76(1.25)	3.76(1.16)	3.54(1.05)	3.71(1.15)
Read a textbook *	3.06(1.25)	1.88(1.27)	2.15(1.07)	2.31(1.30)
Work on problem sets *	2.94(1.39)	1.88(1.30)	2.00(1.00)	2.24(1.33)
Take tests in class **	3.12(1.27)	3.08(1.15)	1.54(.88)	2.73(1.30)
Discuss reading materials in class	3.47(1.37)	2.96(1.43)	2.38(1.12)	2.98(1.38)
Maintain lab notebook **	1.35(.70)	1.56(1.04)	3.00(1.29)	1.84(1.20)
A scripted lab or project in which the students know the expected outcome	1.47(1.07)	2.24(1.59)	1.77(.83)	1.89(1.31)
A lab or project in which only the instructor knows the outcome	1.41(.80)	1.56(.87)	1.92(1.19)	1.60(.93)
A lab or project where no one knows the outcome **	2.41(1.37)	4.12(1.20)	3.62(1.33)	3.47(1.46)
At least one project that is assigned and structured by the instructor	2.65(1.06)	3.56(1.36)	3.00(1.41)	3.15(1.33)
A project in which students have some input into the research process and/or what is being studied	2.88(1.62)	3.72(1.17)	3.54(1.39)	3.42(1.40)
A project entirely of student design **	1.82(1.47)	2.16(1.43)	4.15(1.07)	2.53(1.63)
Work individually	2.76(1.20)	2.44(1.12)	2.69(1.03)	2.60(1.12)
Work as a whole class	2.59(1.37)	2.16(1.28)	2.77(1.48)	2.44(1.36)
Work in small groups	3.24(1.09)	3.88(1.20)	4.15(.90)	3.75(1.14)
Become responsible for a part of the project **	3.18(1.38)	4.20(1.19)	4.31(.75)	3.91(1.25)
Read primary scientific literature	2.94(1.20)	3.36(1.52)	2.92(1.19)	3.13(1.35)
Write a research proposal	1.47(1.07)	1.72(1.10)	2.08(1.38)	1.73(1.16)
Collect data *	3.53(1.18)	4.36(.91)	4.31(.75)	4.09(1.02)
Analyze data	3.53(1.12)	3.88(1.09)	4.31(.75)	3.87(1.06)
Present results orally **	1.82(1.13)	3.60(1.32)	4.15(.80)	3.18(1.48)
Present results in written papers or posters **	2.29(1.40)	4.44(.77)	2.54(1.56)	3.33(1.56)
Critique the work of other students.	2.35(1.41)	2.96(1.40)	3.15(1.07)	2.82(1.35)

ANOVA Sig. * $p < .05$, ** $p < .01$

Table 4. Measures of Perceived Gains in Learning that Took Place

significant difference for taking tests in class, $F(2,52) = 9.37$, $p < .01$. The post hoc analysis revealed Course A had significantly higher gains in learning from all these activities than Course C ($p < .01$). These differences in gains may be attributed to the level of inquiry structure of the research integrated into the courses, and the differentiated emphasis on classroom and research activities between the three courses.

6.1.4 Overall Impressions.

The final ranking items on our survey were used to measure overall impressions of the experience using a five-point Likert scale, with "1" representing "Strongly Disagree" or "Negative Experience" and "5" representing "Strongly Agree" or "Positive Experience" (see Table 5). Students were very positive in their responses to the item suggesting this is a good way to learn science ($M = 4.73$, $SD = .53$), the item regarding asking questions and getting help ($M = 4.71$, $SD = .63$), and the item correlating the experience with a positive effect on their interest in science ($M = 4.55$, $SD = .94$). The outcomes of these items suggest that students had positive affective and cognitive learning experiences. The high mean score for viewing course-integrated UR experiences as a good way to learn science is reflective of both positive cognitive and affective outcomes. The increased interest in science and interaction with getting help are indicators of increases in affective measures related to their UR experience.

We conducted an ANOVA using the course as the factor and the nine items as the dependent variables. The courses were found to vary on only one of these measures (see Table 5). The Level 3 inquiry Course C students were more positive about working with other students, $F(2,52) = 5.57$, $p < .01$, than both the Course A and Course B students. This may reflect the level of responsibility and independence of students engaged in course-integrated UR experiences that are structured at the highest level of inquiry. It may have also been influenced by the study-abroad structure of Course C in which students enrolled in this single biology course, thereby reducing the scope of day-to-day commitments typically associated with a regular semester course load. Additionally, studying abroad itself can greatly impact student independence; this could not be separated from students' perception of gains based on the research experience.

6.2 Qualitative Data

Our analysis continued with an examination of written responses by the students to the question asking them for additional comments regarding their course-integrated research experience. We coded the responses according to indicators of affective perceptions and understanding of scientific research. Terms such as "enjoyed," "disliked," "fun," and "boring" were

Question Content	Course A	Course B	Course C	Total
	M(SD)	M(SD)	M(SD)	M(SD)
Good way to learn subject matter	4.47(.87)	4.56(.92)	4.92(.28)	4.62(.80)
Good way of learning about the process of scientific research	4.71(.47)	4.72(.61)	4.77(.44)	4.73(.53)
Had a positive effect on my interest in science	4.59(.80)	4.52(.96)	4.54(1.13)	4.55(.94)
Able to ask questions in this class and get helpful responses	4.53(.80)	4.72(.61)	4.92(.28)	4.71(.63)
Evaluate your current feelings about your experience **	3.82(1.19)	3.88(1.36)	4.62(.77)	4.04(1.22)
Your experience with other students	2.47(1.74)	3.28(1.54)	4.31(.95)	3.27(1.62)
Would you choose to have another research experience as an undergraduate	3.65(1.17)	3.48(1.12)	3.85(.99)	3.62(1.10)

** $p < .01$

Table 5. Measures of Overall Impressions

used as codes for affect. Terms such as "understanding," "learned," "thinking," and "know more" were used to code for cognitive understanding.

Of the 55 participants, 24 provided a written response, and of those responding approximately 60% provided an affective narrative and about 80% responded with comments that could be coded as having cognitive content. Most of the affective comments were similar to this response from a student in Course A:

> *"I really enjoyed my semester and am glad I took the course."*

Many responses from the students enrolled in the three courses communicated how they enjoyed the courses (affective perceptions) and learned more about science (cognitive influences) submitting passages similar to this participant from Course B:

> *"I really enjoyed the research in this class especially in terms of working with other students. [The faculty] made the experience enjoyable and pushed us to think scientifically - so happy I was able to take this course!!"*

A participant from Course A wrote:

> *"I really enjoyed [the faculty's] research but, actually, the entire class was wonderful. I still tell other students/friends/parents that I probably have never learned more from a single class. It was very pivotal for me in how I look and feel about science. Thanks!"*

It is apparent that regardless of the level of inquiry, the course-integrated research projects affect how the undergraduates viewed science both as a career and as an intellectual endeavor. The consistency within several of the affective perceptions and cognitive influences among the three courses suggests that regardless of the levels of inquiry, students had positive feelings about their research experiences and perceived the experiences as beneficial to their learning.

There were some detectable differences in the responses by the participants with more than one response from a Course C student referring to the scientific method. This Course C participant wrote:

> *"I really liked how we got to choose our own research project for this course. It is unfortunate that the class is so short and we could not do a more in depth study. But it serves as a very good baseline to get an idea of how to design your own research and understand what needs to go into it for it to become successful. I think anyone who does this class and has a good understanding of the scientific method will gain a lot from this class even though the research is not too complex."*

Although some students from Courses A and B did comment on learning more about science, none of them provided any reference to "the scientific method." This may reflect the Level 3 inquiry structure of the research by Course C students which required high levels of engagement and responsibility and in turn lead to deeper thinking about scientific research.

The only negative comments shared by students from all courses were related to working in groups. This comment from a student in Course B typified the perceptions shared by several others:

> *"I learned that working with groups will not help me to learn more about the research. I [would]rather work [by] myself at my own pace."*

It appeared that the participating students struggled with task distribution and sharing responsibility for the research projects with their peers. Yet these were the only negative comments shared, indicating that group dynamics may need attention at all levels of inquiry when integrating a research component into an undergraduate course.

7. Discussion

Consistent with results of previous research, participants from all three of our study courses reported cognitive and affective benefits from their UR experience (Hunter, Laursen, & Seymour, 2006; Lopatto, 2004, 2007; Trosset, Lopatto, & Elgin, 2008). Through an examination of participants' responses to our assessment instrument, we found that all undergraduate course-integrated UR experiences had beneficial affective and cognitive outcomes. As a group, participants expressed gains in perceived knowledge and interest in science, which supports the notion that students benefit from engagement in course-integrated undergraduate research experiences. Further, our evidence supports a critical examination of the goals of the traditional lab experience and whether those goals can be met with activities that are more consistent with authentic scientific research situations. This outcome provides justification to re-examine the structure of the undergraduate science curriculum and give additional consideration to course-integrated research activities to enhance undergraduate science education.

Also, consistent with other research, we found that course-integrated research experiences can have many of the same benefits and gains as one-to-one experiences (Trosset, Lopatto, & Elgin, 2008). The students communicated positive affective outcomes; they enjoyed the experience and would do it again. The students also communicated beneficial cognitive outcomes indicating that they learned more about science. This supports our first hypothesis in which we anticipated all students would view the processes as worthwhile and voice appreciation for the experience. However, our research also indicates that measured outcomes from research experiences differed based on the level of inquiry structure. Students engaging in the Level 3 inquiry structure research communicated higher levels of confidence in doing research, which may be due to their research experience or their entire study abroad experience. However, this outcome was inconsistent with our hypothesis and suggests that students' affective outcomes may be related to the structure of their experience. Students' differential affective outcomes based on their experiences provided the answer to our first research question. The variation in responses indicated that there is a relationship between the level of inquiry structure of the research experience and the students' feelings and attitudes toward their UR experience. However, the lack of a significant difference between the confidence levels of the Course B and Course C students suggests that there may be a threshold of effect related to inquiry levels such that affective outcomes for Level 2 are comparable to those of Level 3. The determination of the specific impacts of inquiry levels of UR experiences on student confidence and other related outcomes is an excellent direction for future research.

Our results support our second hypothesis; that students engaging in research experiences that require high levels of independence and responsibility learn more about scientific research. The Course C participants who were engaged in research experiences with a Level 3 inquiry structure expressed greater gains in knowledge of science research, in scientific methods, and confidence in their research abilities. Further, Course C students expressed gains in research activities at levels higher than their peers in Courses A and B, who engaged in research activities structured at lower levels of inquiry. It is interesting to note that even though Course B and Course C did not differ in the proportion of students with prior research experience ($p>.05$), Course C had many more significant gains than Course B. This suggests that prior experience may not be critical to experiencing significant gains in Level 3 inquiry activities. This outcome challenges the notion that novice learners may not gain as much from full inquiry activities as they may from more structured inquiry experiences (Settlage, 2007). The differential cognitive outcomes based on their experiences provided the answer to our second research question. It appears there is a relationship between the structure of the research and students' perceived learning related to their experiences. However, there may be nuanced differences in perception of learning if the UR experiences levels of inquiry are proximal, as with Course B and Course C.

The UR experience structured at Level 3 inquiry (Course C) resulted in greater positive influences on student perceptions and understanding of science as well as their confidence and attitudes about science. This may be attributed to the Level 3 inquiry structured research experience which required high levels of student independence and responsibility for doing research. Course C was a study abroad program, which is arguably costly and resource-intensive. However, courses could be structured to integrate UR experiences at the same level of inquiry and investigate the local environment, which would maintain the same basic structure but substantially reduce the cost. We maintain it is the levels of student responsibility for the research (level of inquiry) that was the primary influence on the participants' perceptions of the benefits of the course on their understanding and attitudes toward research. This has important implications for the design and implementation of course-integrated UR experiences. Yet the distinction between the benefits of the inquiry structure of Course B and Course C may not be clearly delineated, indicating that there may be a threshold in gain in relation to level of inquiry.

Even though our results support the notion that all benefited from the course-integrated research experience, we detected multiple outcomes in which the gains from experiences and in learning of scientific research were significantly greater for research experiences structured at higher levels of inquiry. Conversely, the participants who engaged in course-integrated research structured at lower levels of inquiry communicated significantly higher gains from traditional classroom experiences and importance for course activities for learning (e.g., reading textbooks, testing), that are not typically associated with scientific research. This suggests the students engaging in research activities structured at lower levels of inquiry may be more prone to viewing the experience as consistent with typical course exercises and not unique opportunities for learning science. Likewise, the students enrolled in the courses with UR experiences structured at higher levels of inquiry may not view traditional learning processes as salient to the objectives of the course. This outcome is most likely reflective of the differential emphasis on instructional activities and resources between the courses and the subsequent importance and influence placed on the processes on in relation to student learning. Our data shows that course-integrated UR experiences that are structured to increase learner levels of responsibilities and independence provide students with a different perspective of the activity, resulting in different cognitive and affective outcomes.

The results of our study must be considered in the context in which the investigation of the undergraduate course-integrated research experiences took place. There were two different instructors for the three courses, each with unique teaching styles, teaching different course content, and attending to different curricular objectives. It is important to note that higher proportions of prior research experiences of Course B and Course C participants compared to Course A may be used to explain some of the differences in the measures of cognitive and affective gains between these groups. However, the numerous measures in which Course B outcomes differed from Course C also indicates the influence of prior experience is most likely superseded by the structure of the course-integrated UR experience. The influence of prior experience on the outcome measures of course-integrated UR experiences is an excellent topic for future studies.

The courses included in this study were not designed to be taken in a sequence commensurate with the UR levels of inquiry. Although it was possible for a student to take these courses in this sequence, it was highly unlikely that this occurred. However, this does bring up an interesting issue regarding the potential benefit of sequencing courses that integrate UR experience to scaffold the levels of inquiry from guided to independent. Our evidence does indicate experience is an important factor influencing student perceptions of their course-integrated UR experiences, and scaffolding holds the potential for preparing students to experience success with increasingly independent research. This is also an excellent direction for future research.

Overall, it appears that students benefit from course-integrated research activities, with the greatest outcomes perceived by those who engaged in experiences structured at higher levels of inquiry, Courses B and C. Further, the overall positive gains in affective and cognitive measures supports the offering of course-integrated research experiences in place of, or in addition to, one-to-one UR experiences. Course-integrated experiences provide a practical solution to constrained budgets and the limited availability of opportunities which restrict the number of undergraduate students who are able to engage one-to one scientific investigations.

Our results have important implications for instructors considering the integration of course based research. First, it appears that course-integrated UR experiences are acceptable alternatives to the traditional one-to-one pairing. Second, our data suggests there are benefits to increasing the level of student responsibility and engagement in UR experiences. Third, the outcomes of course-integrated UR experiences include perceived gains in affective measures such as attitudes and goals and cognitive measures, such as knowledge and skills. It is apparent that course-integrated UR experiences can achieve the desired goals of helping students gain clarity in selecting careers in science and become acclimated to the culture of scientific research. The challenge lies in determining the optimal configuration of inquiry in UR to maximize student learning and appreciation for science and research.

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Appendix

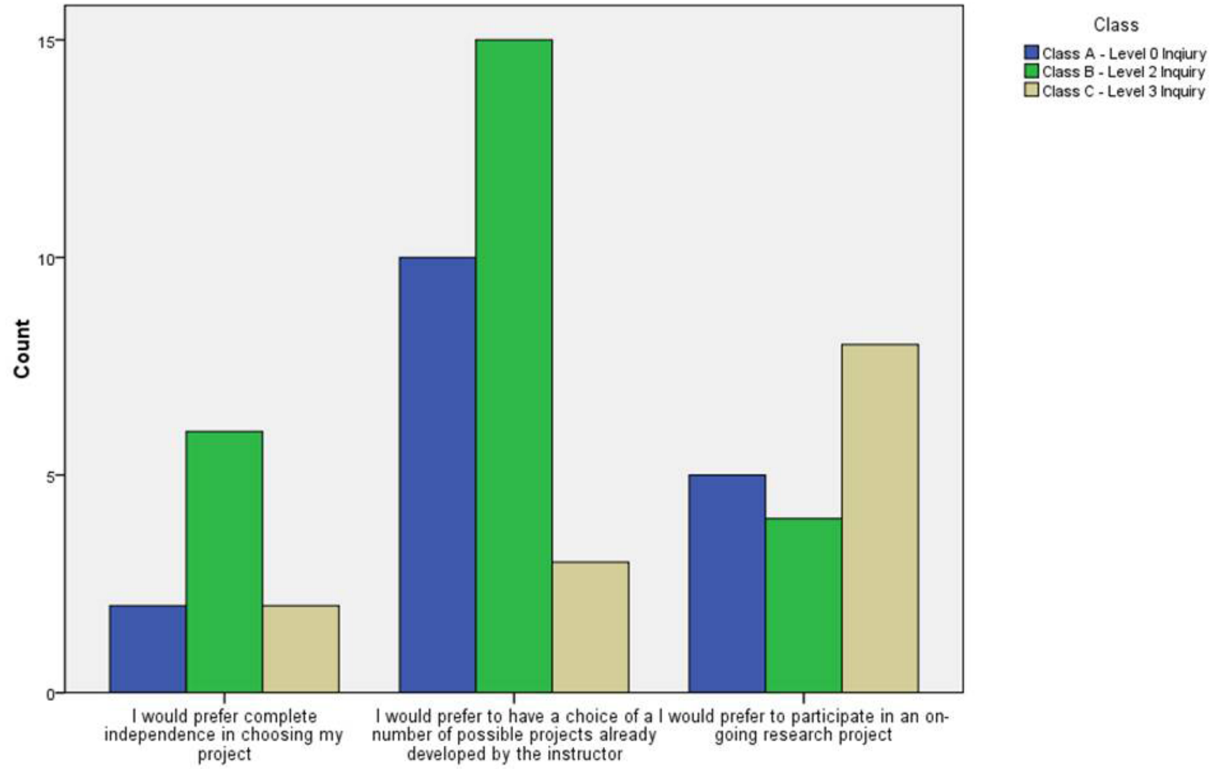

Figure 2: Distribution of participants' responses to the question "If you were doing a research experience in a class in the future, which would you prefer?"

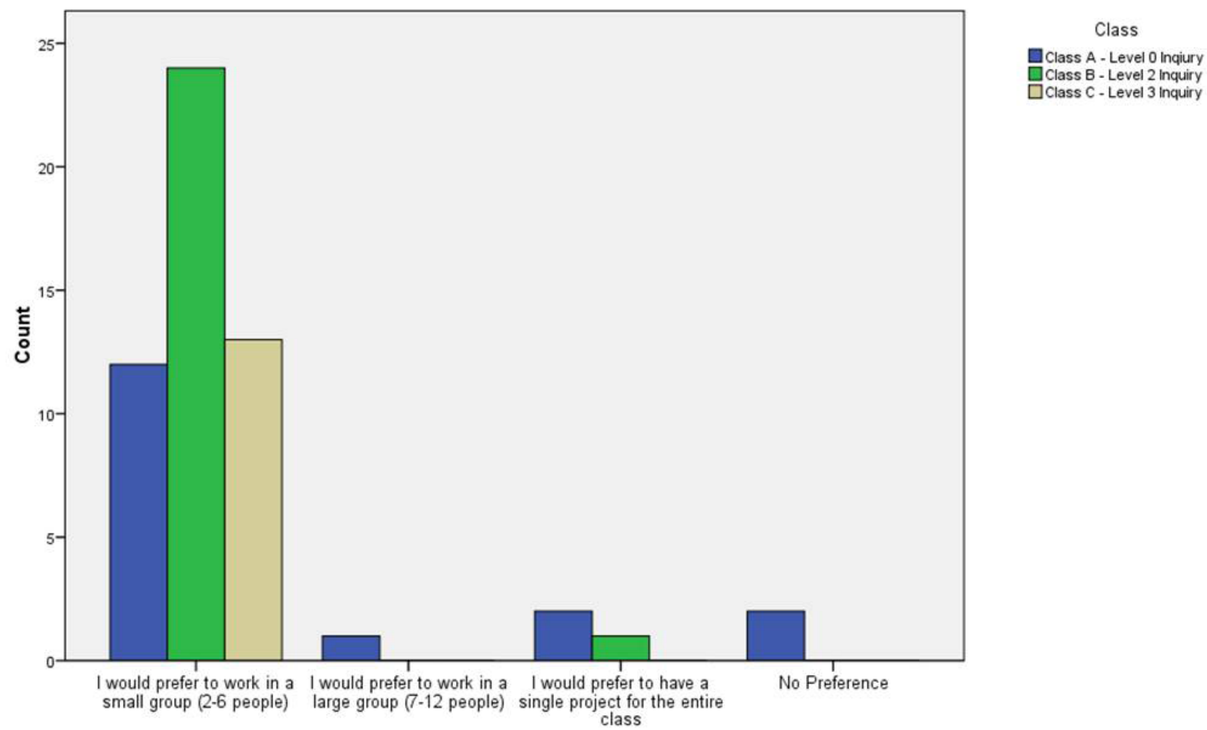

Figure 3: Distribution of participants' responses to the question "If you were doing a research experience in a class in the future, which would you prefer?"