SPECIAL TOPICS

Implementing a course-based undergraduate research experience to grow the quantity and quality of undergraduate research in an animal science curriculum

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Abstract

Undergraduate research involves experiential learning methods that helps animal science students gain critical thinking skills. There is high demand for these opportunities. For example, 77.9% of incoming freshmen in the Department of Animal Sciences & Industry at Kansas State University in Fall 2017 and Fall 2018 planned to conduct research sometime during their undergraduate career (422 of 542 students). Conventional, one-on-one mentoring methods in the department were only serving 1.7% of the undergraduate population (21 of 1,212 students). This creates a unique challenge of increasing the number of undergraduate research opportunities, while maintaining the impact of individualized experiential learning.

One method to address this challenge is the incorporation of a course-based research program. In this model, research projects are conducted during a conventional semester during scheduled classroom hours, with project components divided into 3 sections: (1) research preparation, including compliance requirements, hypothesis testing, experimental design, and protocol development; (2) data collection; and (3) data interpretation and dissemination. Students collect data as a team, but individually develop their own research abstract and poster to maintain a high level of experiential learning. By teaching multiple sections of this course per semester and incorporating the concepts into existing laboratories, 13.5% of students in the department completed undergraduate research in the 2018–2019 academic year (162 of 1,197 students). To monitor the quality of these experiences, student critical thinking ability was assessed using the online Critical Thinking Basic Concepts & Understanding Test (Foundation for Critical Thinking, Tomales, CA). Undergraduate research experiences increased \( P = 0.028 \) the growth in student critical thinking score, but the type of research experience did not influence assessed skills \( P > 0.281 \). Thus, course-based undergraduate research experiences may be an option for growing the quantity and quality of undergraduate research experience in animal science.

Key words: assessment, critical thinking, student, teaching, undergraduate research

Introduction

Undergraduate education has 2 primary outcomes: (1) installation of knowledge and (2) development of talent. Conventionally, research-focused aims within the animal sciences are centered on increasing the knowledge across species and disciplines through the generation of new information and
evolved interpretations. However, undergraduate research shifts efforts to be more student-focused. In the case of undergraduate research experiences, the primary outcomes become a student learning and skill development. Data generated during the process must still be novel, relevant, and meaningful, but provide a secondary role, and instead serve as the tool to influence student learning and talent development.

The value of undergraduate research experiences is rarely disputed (Kardash, 2000; Waite and Davis, 2006). Historically, these experiences have served as a method to expose students to graduate school pathways, but have evolved to have broader impacts across undergraduate students. For example, undergraduate research is frequently cited as a transformational experience that helps students more fully apply knowledge learned in the classroom to real-life scenarios, thereby improving retention of the information (Hunter et al., 2007). The experience is oftentimes the first exposure of a student to the formal mentoring process, which lays a foundation for subsequent mentoring relationships that have proven predictive of professional success (Landrum and Nelsen, 2002). Finally, the undergraduate research experience has been demonstrated to develop professional skills, including improvements in critical thinking, problem solving, independence, and innovation (Kardash, 2000).

As the number and complexity of grand challenges in animal agriculture expand, it becomes vital to instill these skillsets in all animal scientists. Graduates of animal science programs must have the training to interpret data to make science-based decisions; whether that be as formally trained researchers, veterinarians making recommendations for appropriate pet foods, ranchers evaluating the costs and benefits of different vaccine programs, or industry representatives selling products to meet various needs. Students understand the necessity of gaining these skills during their undergraduate career. An average of 77.9% of incoming freshmen in the Department of Animal Sciences & Industry at Kansas State University in 2017 and 2018 planned to conduct research sometime during their undergraduate career (422 of 542 students; Jones et al., 2019). This led to a unique challenge, where student demand for these transformational activities far exceeded conventional department capacity. For example, the conventional model of 1:1 student:faculty mentor ratio accommodated about 20 students in 2013 to 2015, which was only about 2% of the student population in the department (Jones et al., 2019). Because opportunities were so rare, they were largely limited to only upperclassmen who had expressed an interest in graduate school. The remaining students were left to seek research opportunities in other departments or not at all.

To address this challenge, a variety of undergraduate research models were considered, including methods to increase the number of students accommodated through conventional participant-based undergraduate research, the role of an introductory research seminar, or the development of a research experiential course. Jordan et al. (2014) reported learning gains when students were exposed to these different undergraduate research methods, with the research experiential course having the greatest impact on learning gains. Other course-based research experiences had been reported (Waite and Davis, 2006), but none, to the best of our knowledge, had been translated to animal science. The objective of this research was to increase the number of meaningful undergraduate research opportunities without sacrificing student learning gains or negatively impacting other departmental resources. The hypothesis was that offering a course-based research experience would accommodate greater numbers of undergraduate researchers, with those students having similar gains in critical thinking ability as students conducting conventional participant-based undergraduate research experiences.

Materials and Methods

All experimental procedures (proposal #8609) were determined by the Kansas State University Research Compliance Office as exempt under the criteria set forth in the Federal Policy for the Protection of Human Subjects, 45 CFR 46.101(b)(1)(ii).

Increasing Conventional Undergraduate Research Experiences

To grow the quantity of conventional, participant-based undergraduate research experiences, 3 barriers were addressed that were believed to limit the number of mentees accepted by a faculty undergraduate research mentor. These included: (1) providing financial assistance (up to $1,500 per mentee) for faculty to purchase supplies necessary for conducting undergraduate research; (2) facilitating completion of mentee compliance requirements, such as the set forth by the Institutional Animal Care and Use Committee, Occupational Health and Safety Program, or Institutional Review Board before the student beginning a research experience; and (3) strategically matching mentees with their undergraduate research mentors.

To facilitate the process of more strategic matching, it was first important to more fully elucidate the types of research projects available to students. Three participant-based project types were identified: (1) shadow projects, where a student works individually with a graduate student or faculty member who is conducting research, but is not solely responsible for any portion of the research; (2) add-on projects, where a student helps a graduate student or faculty member conduct an existing project, but a specific response criteria is identified for the undergraduate student to lead; and (3) stand-alone projects, where a student is mentored by a graduate student or faculty member, but has primarily responsibility for all parts of the research. All these projects were deemed to have the potential to be meaningful undergraduate research experiences provided that the undergraduate student is exposed to the entire research process and independently communicates the results in both oral and written form.

Students interested in conducting an undergraduate research experience completed a 1-page form that described their preferred project type (shadow, add-on, or stand-alone), completed coursework, and ranked their interest in conducting research in varying species and disciplines. These forms were then used to build a searchable and filterable database to easily identify students whose interests match with a specific faculty member when they have an opportunity available. Additionally, student maturity and independence were considered when recommending mentees. For example, some faculty researchers were better match with underclassmen because they provide more direction and guidance, while other faculty are best suited for upperclassmen because they expect a greater level of independence and innovation from undergraduate researchers. When faculty had opportunities available, they were offered a short list of 3 to 7 students that best met their research team, so that a faculty member could either interview and select their own mentee or request a single student be recommended.
Development of a Course-Based Undergraduate Research Experience

To increase the undergraduate student:mentor ratio, a course-based undergraduate research experience was created. This 2-credit course was part of the academic load of a student during a conventional 15-wk semester and counted in the curriculum toward a departmental elective. The course was divided into 3 sections: (1) research preparation; (2) data collection; and (3) data interpretation and dissemination. In the research preparation section, students complete the compliance requirements necessary for the project and discuss the ethics of using animals for research purposes. The scientific method is reviewed, with in-depth application of developing a hypothesis for the project, identifying its experimental design, and developing a research protocol. During the data collection section, students conduct the research experiment and collect data as a group. Lecture topics include concepts of data management, addressing outliers, and statistical power with replication. Throughout the data interpretation and dissemination section, students are exposed to statistical analysis software and build data tables from software output. Additionally, students learn interpretation of data from their own project, as well as others published in relevant literature. Guest lecturers describe how scientific results are translated to producer and public audiences. Finally, students individually develop their own research abstract and poster to maintain a high level of experiential learning. At the end of each semester, students present their research poster in a departmental research forum. Course-based project topics have included antibiotic replacement in poultry diets, swine health, meat goat nutrition, food microbiology, and consumer preference of beef. Ideally, research projects are 5 to 6 wk in length to allow for the research preparation, and data interpretation and dissemination sections; all key components of student learning.

Solicitation of Financial Support

Funding was an initial barrier to increasing the number of conventional, participant-based undergraduate research experiences as well as to course-based research experiences. A 2-phase approach was used to mitigate this challenge. First, the topics for the course-based research projects were selected based on industry relevance, which allowed for the solicitation of funding through conventional grants and contracts. For example, grants from the Kansas Corn Commission were awarded by proposing projects through Requests for Proposals. Other grants were awarded by industry partners through traditional pre- and post-award contracts to conduct research projects, including those from Ceva Animal Health (Lenexa, KS), Tyson Beef (Springdale, AR), Dairy Nutrition Plus (Ames, IA), 3M (Maplewood, MN), ADDCON (Bitterfeld-Wolfen, Germany), and Hy-Flains Feedyard (Montezuma, KS). In some instances, funding was awarded solely due to the merit of the proposed research, while other invested in educational opportunities for students while simultaneously answering a relevant research question.

While conventional industry funding streams funded the project costs associated with course-based research experiences, programmatic needs for participant-based project supplies, research posters, facilitation of the end-of-semester research forum, awards, and travel remained. With the assistance of the Kansas State University Foundation, a potential donor was identified; an alum of the department and beneficiary of undergraduate research. The Dr. Mark and Kim Young Undergraduate Research Fund in Animal Sciences and Industry was established in 2017 with a 5-yr, $250,000 gift.

Assessment of Student Learning Gains

With the new options for students to conduct undergraduate research experiences, assessment of student learning gains became increasingly important to test the hypothesis that course-based provided similar improvements in student critical thinking as conventional experiences. An anonymous, online self-assessment survey was completed within 2 wk of students completing the undergraduate research experience. The survey asked 13 independent questions, with a 5-point Likert scale used for response options as described by Cavus and Uzunboylu (2009). Responses could include (1) strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree. Of 181 students, 178 consented to their survey responses being used for research purposes; 47 of which completed conventional, participant-based research and 131 completed course-based research experiences. There were differences in the classification of students completing projects in our data, with 69% of students completing the course-based research experience as freshman or sophomores, compared with only 11% of students completing participant-based research experiences (Figure 2). Future research will compare differences among project types, particularly among students who have completed both experiences.

In addition, the Online Critical Thinking Basic Concepts & Understanding Test (Foundation for Critical Thinking, Tomales, CA) was completed by students in the Department of Animal Sciences & Industry as part of a freshman-level orientation class in Fall 2017 and Fall 2018 (baseline) and again after their completion of a sophomore-level departmental nutrition course in Spring 2018 and Spring 2019 (endline). Student critical thinking ability was reported as a percentage on a 100-point scale. All students (672) total students chose to complete the online test instead of the alternative course assignment, a 5-page paper on the value of critical thinking to animal scientists. Of these, 618 students consented to their scores being used for research purposes.

Data were analyzed using SAS (v. 9.4, Cary, NC). For students completing the survey, responses were analyzed using the TTEST procedure to compare differences among students completing undergraduate research as a conventional, participant-based experience or as part of a course-based research experience. Assessed student critical thinking score was analyzed using the GLIMMIX procedures as a nested design, with the whole plot consisting of students that had not completed an undergraduate research experience vs. those that had, regardless of experience classification, and the subplot of students completing conventional, participant-based research vs. those completing course-based undergraduate research experiences. Differences were considered significant if P < 0.05 and marginally significant if 0.05 < P < 0.10.

Results and Discussion

Quantity of Meaningful Undergraduate Research Experiences

Efforts to increase the number of conventional undergraduate research experiences in 2015–2016 led to a 48% increase in the number of opportunities available to students (21.5 students enrolled in undergraduate research experiences in 2013–2014
and 2014–2015 academic year vs. 32 in the 2015–2016 academic year; Figure 1). While this was a substantial improvement, it only served 2.6% of the student population at the time (32 of 1,214 students) and was determined to be the maximum capacity of departmental faculty using a conventional model. By offering a new course-based undergraduate research class and incorporating the course-based model into an existing class laboratory, the number of students enrolled in courses with a meaningful undergraduate research experience expanded to 13.5% in the 2018–2019 academic year (162 of 1,197 students), with 37.7% of graduating seniors in Spring 2019 (57 of 151 students) reporting that they completed some type of undergraduate research during their academic career. While this progress is promising, it still falls short of the reported demand of 250 undergraduate research opportunities available/year and 78% of student population planning to conduct undergraduate research.

Quality of Undergraduate Research Experiences

Student perception of their undergraduate research experience was highly positive, with little difference among the types of research experience. There was no evidence ($P > 0.10$) that type of research experience impacted student perception of its value or success for 9 of the 12 survey questions (Table 1). There was marginally significant evidence that students completing co-research experience were more likely to believe the following statements were accurate: “I have experience with computers and software to analyze data and apply it to animal science,” “I had adequate guidance from my undergraduate research mentor,” and “The undergraduate research experience helped me identify if research may be a future career path.” While there is little evidence comparing types of undergraduate research experiences in the literature, these findings are most comparable with those of Jordan et al. (2014), who reported significant increases in student ability to analyze data, independence, and career clarity when first year students conducted a research experiential course compared with a participant-based research experience. In that study, however, mean learning gains for nearly all assessed categories were greater when students completed a course-based vs. participant-based experience, while there was no discernable difference in most of the data presented here. These differences may have been due to differences in assessment, where our students were self-reporting the accuracy of statements using an anonymous survey, while student learning gains in Jordan et al. (2014) were determined by their mentors. Additional differences include that undergraduate research experiences included freshman through seniors, while those in Jordan et al. (2014) were only first year students.

The online critical thinking examination is a more objective assessment of the quality of undergraduate research experience. This examination focuses on the basic concepts and principles of critical thinking, and its consequential validity was demonstrated by Elder and Paul (2007). Previous research by the current authors described that perceived critical thinking ability of students collected by a self-reported survey is similar to that of the assessed score derived by the same online exam used in this research, but that first generation, military, and underrepresented minority students perceive their critical thinking ability to be less than their assessed score (Jones and Hock, 2018). Furthermore, first semester GPA, but not ACT score, was correlated with the score from the online assessment (Jones and Hock, 2018). While student demographics were not included in the present evaluations, Bangera and Brownell (2014) suggested that course-based undergraduate research experiences may be a solution to overcoming the challenges faced by minority or first-generation college students that seek research experience. These authors cited barriers such as lack of awareness of research opportunities, not comprehending the advantages of participating in research, lack of interaction with research faculty, and financial or cultural barriers (Bangera and Brownell, 2014). When using the examination to evaluate differences in students conducting undergraduate research experiences in this experiment, we found that there was no evidence in critical

![Figure 1](image-url) The number of students enrolled in courses that include a meaningful undergraduate research experience in the Department of Animal Sciences & Industry at Kansas State University. Efforts to increase the number of conventional, participant-based, undergraduate research opportunities began in 2015–2016, and course-based undergraduate research experiences began in the 2016–2017 academic year.
Furthermore, we learned that undergraduate mentees. Furthermore, we learned students. Second, our ability to grow the quality of conventional, program can evolve to fit the needs of the department and its environment that necessitates evaluation of programmatic and coordination activities are valued. Furthermore, it creates included in formal evaluations annually and for the purpose of allowing these efforts to be part of their formal job duties. Allowing these efforts to be with the responsibility of coordinating undergraduate research there is value in designating an individual faculty member tasked with others implementing undergraduate research programs. First, several pitfalls and keys to success that we hope can be beneficial thinking in freshman biology majors.

Throughout the process of these efforts, we have identified several pitfalls and keys to success that we hope can be beneficial to others implementing undergraduate research programs. First, there is value in designating an individual faculty member tasked with the responsibility of coordinating undergraduate research as part of their formal job duties. Allowing these efforts to be included in formal evaluations annually and for the purpose of promotion helps communicate to all those involved that time and coordination activities are valued. Furthermore, it creates an environment that necessitates evaluation of programmatic goals and accomplishments, so the undergraduate research program can evolve to fit the needs of the department and its students. Second, our ability to grow the quality of conventional, participant-based undergraduate research experiences was dependent upon matching the personality and style of the faculty mentor with undergraduate mentees. Furthermore, we learned that graduate students can play an important role in facilitating their undergraduate research program of the faculty mentor by helping select student researchers and serve as supervisors. This also provides supervisory experience to graduate students and can potentially increase the capacity of faculty mentors to accept undergraduate mentees. Finally, we learned that the course-based undergraduate research experience must feature a project that is relatively simple, with a straightforward experimental design and clear controls, and should be no longer than 6 wk in length. This allows for sufficient preparation time, so students are clear about their expectations before beginning the experiment, as well as several weeks to help students understand results and implications before their presentation of results.

Potential limitations of this research include that it was conducted over only 3 yr at one landgrant university. Additional research is needed to better understand the application of this research over a longer time period as student populations change, at additional time points to determine the impact of prior coursework and preparation impact these findings, with other undergraduate experiences outside of research, and at other universities and colleges with varying student population and curriculum.

In summary, undergraduate research experiences can help develop an animal science workforce with skills to interpret data to make science-based decisions, which is needed regardless of the resultant occupation of a student. However, the demand for such opportunities frequently outweighs the capacity of a conventional model where students are mentored in a 1:1 ratio by faculty. The number of conventional opportunities can be increased by providing financial assistance for faculty to purchase supplies, facilitating the completion of mentee compliance requirements, and strategically matching mentees with mentors. However, this still results in undergraduate research opportunities being reserved for upperclassmen interested in graduate school. To increase the exposure of a broader undergraduate audience to the benefits of undergraduate research, a course-based research experience can increase the

| Table 1. Student perceptions of participant-based or course-based undergraduate research experiences. |
| Statement | Participant based (n = 131) | Course-Based (n = 47) | SEM | P-value |
| The undergraduate research experience met my expectations. | 4.8 | 4.9 | 0.23 | 0.872 |
| I can apply the scientific method to answer research questions. | 4.5 | 4.6 | 0.24 | 0.905 |
| I am competent in quantitative skills, such as data analysis. | 4.5 | 4.4 | 0.23 | 0.824 |
| The undergraduate research experience improved my critical thinking skills. | 4.6 | 4.6 | 0.24 | 0.923 |
| I can apply critical thinking skills to distinguish fact during the interpretation of results. | 4.6 | 4.8 | 0.21 | 0.507 |
| I have experience with computers and software to analyze data and apply it to animal science. | 4.1 | 4.5 | 0.19 | 0.087 |
| I have an appreciation for ethical practices, such as the use of animals for research purposes. | 4.7 | 5.0 | 0.20 | 0.338 |
| I can work as a team. | 4.9 | 5.0 | 0.22 | 0.769 |
| I had adequate guidance from my undergraduate research mentor. | 4.6 | 5.0 | 0.18 | 0.064 |
| The undergraduate research experience made me want to conduct additional research in the future. | 4.4 | 4.3 | 0.22 | 0.784 |
| The undergraduate research experience helped me identify if research may be a future career path. | 4.2 | 4.6 | 0.18 | 0.076 |
| I would recommend undergraduate research to a friend. | 4.8 | 4.9 | 0.23 | 0.822 |

1Student survey responses to the question, “How accurate is this statement” using a 5-point Likert scale ranging from 1: strongly disagree to 5: strongly agree based on their completion of a conventional, participant-based undergraduate research experience vs. a course-based research experience.
quantity of undergraduate research experiences that can be offered without compromising the quality of student learning.

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