

The Hogsback Project: A Model for Multidisciplinary Integrated Research on the Block

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Abstract

At the University of Montana Western, we emphasize making experiential learning the focus of our institution. We feel that students profit from research experiences that connect courses across disciplines, especially in the general education curriculum. The Hogsback project was designed to engage students in the cycle of research by investigating how individual worker behaviors of the western harvester ant, *Pogonomrymex occidentalis*, affect their environment. To facilitate implementation, professors incorporated the Hogsback research into existing course structures and projects. We established a student-run journal, called *The Hogsback Journal*, for research to be disseminated to involved participants. To date, 536 students, thirty-four classes and twelve professors have been involved in the research. Students have participated in a wide variety of fields including soil science, statistics, mathematical modeling, ecology, biology, and geology. Paper submissions to *The Hogsback Journal* far exceeded expectations with fifty in fall 2021, fifty-nine in spring 2022, and fifty-six in fall 2022, becoming the hub through which research is disseminated. Based on the Hogsback project, we present a multidisciplinary approach to creating experiential course projects that we call HUB research that applies outside of STEM disciplines. We demonstrate how to implement a HUB research project using existing courses and structure of the block. Once established, a HUB research project serves as a central organizing feature for research that students can participate in to fulfill the educational goals of their courses. HUB architecture allows students to engage in successive courses giving them a more sophisticated understanding and perspective from different disciplines. Research is driven by an inquiry-based research cycle. As it evolves at block-accelerated speed, HUB research is a powerful engine for multidisciplinary research.

Keywords: multidisciplinary, inquiry-based, undergraduate research, experiential learning

Introduction

At the University of Montana Western, we have always had a focus on experiential learning which was part of the motivation for the faculty-driven (faculty refers to those teaching courses or doing research at the university) transition to the block schedule (Thomas & Roberts, 2009). Our concise working definition of experiential learning across the wide range of disciplines we offer has been *to provide opportunities for each student to engage in the authentic practice of each discipline*

(The University of Montana Western Catalog). By *authentic practice*, we mean that students are provided with both the thought processes of the relevant discipline and the opportunities in the field, laboratory, historical library, museum collection, and local business endeavor necessary to engage in thoughtful exploration within each discipline. We want our students to be able to navigate in each discipline and to put their thoughts into action (Kolb & Kolb, 2017; Thomas & Roberts, 2009).

A group of faculty members from various disciplines decided to tackle this deficiency by engaging students in a multidisciplinary research project which we call the Hogsback project. In order to link multiple disciplines in cooperative research, we focused on bringing portions of the research cycle (Figure 1) into our classes to integrate research into the block. A key aspect of this cycle is that each portion of the research cycle (blue versus yellow) informs the other. By using this cycle for research, we brought together research at different levels, beginning with freshman students getting an introduction to research all the way to senior students doing independent research project, across diverse disciplines.

In addition to having the students engage in multidisciplinary research, we also wanted them to use an inquiry-based approach (Huber, 2009) in which learners determine the direction of the research through developing and testing hypotheses related to the overarching project and the project evolved through time. Inquiry-based research is best described by Wilhelm von Humboldt (1810):

In contrast to other learning methods, inquiry-based learning is characterized by the fact that learners shape, learn and deliberate on the process of a research project, which is aimed at obtaining insights that are of interest to third parties, doing so throughout all the essential phases of said project; from developing questions and hypotheses, selecting and implementing the methods, through testing and presenting the results, either by working independently or in active collaboration with an overarching project. (Huber 2009, p. 11, translated)

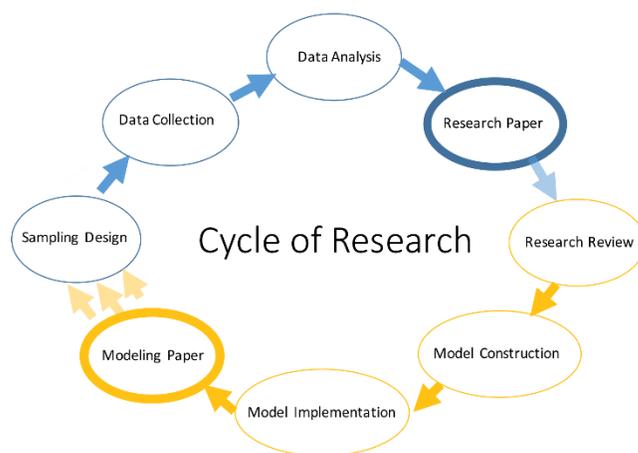


Figure 1 The Cycle of Research

Note. The cycle of research that we use as a model to teach students about research in our classes. In the blue portion students learn to design experiments, collect data, analyze their data, and write research papers. In the yellow portion students learn to read research papers for ideas, write mathematical models, implement those models, and write papers with testable predictions for future research.

We needed a natural ecosystem that would provide ample research opportunities to satisfy these disciplines. We decided to focus on researching the individual behaviors that *Pogonomyrmex occidentalis* (western harvester ants, Figure 2) display in their environment. There is a rich research site north of Dillon, Montana, near the Hogsback geological formation, that is dominated by this species of ant. Workers clear vegetation around their intricate nests; the above-ground portion is an asymmetrically shaped mound (Figure 3) covered by fine gravel with a nest entrance that usually faces south or southeast (Cole, 1994; Wheeler & Wheeler, 1983). Harvester ant workers forage mainly for grass seeds which they individually bring back to the nest. Through their preference for certain species of seed, they change the species composition of the plant community in their foraging range (Gosselin et al., 2016). By constructing elaborate nests, they change the profile of the soil in the area around their nests. Simply because of the vast colony size, they modify the invertebrate and vertebrate biota of this ecosystem. The modification of their environment makes these ants ecosystem engineers. Our research program investigates how individual ant behavior leads to ecological and geological transformation of their environment (MacMahon et al., 2000).



Figure 2 Head of *Pogonomyrmex occidentalis* worker

Note. Photographer: April Noble, specimen code: CASENT0005718, From www.antweb.org



Figure 3 Ant nest

Note. Example of a *Pogonomyrmex occidentalis* gravel nest with the vegetation cleared around it. In the background you can see the Hogsback for which the research project is named.

Using the Hogsback project as an example, we will outline implementing a HUB research project by creating inquiry-based experiential learning projects. The block schedule helps to facilitate these projects to give students the time necessary to get an in-depth experience of research in their field of study.

Implementation

In the last semester of 2021, we implemented the Hogsback project through individual courses by aligning Hogsback research goals with existing course goals and projects. This greatly simplified implementation as the Hogsback research fit nicely within our existing course structure, course objectives, and course schedules. In addition, the implementation required no extra time-

commitment by students or faculty. To create a sustainable project, each class was asked to provide questions that other classes could answer. Each class contributed according to their level of scientific and mathematical ability. In some courses students acquired the skills to design samples, while in other courses students collected data and analyzed it. When students wrote research or modeling papers as part of their class projects, these papers were submitted to *The Hogsback Journal*, a student-run publication. *The Hogsback Journal* acted as the hub that connects the students and drives the research cycle for our classes.

Results

Over the last three semesters (the last semester of 2021 when the project was implemented and 2022) we had 536 students, thirty-four classes and twelve professors (professors refers to those teaching courses or doing research at the university) involved in the Hogsback project. Of the participating students, twenty-six percent took more than one block with some students doing projects for five or six blocks. Students who participated in more than one block gained a more sophisticated understanding of the Hogsback project (from the different research methods employed in their different courses and also moving from lower level to upper level courses) and engaged in more parts of the research cycle (Figure 4).

In addition to having provided opportunities for students to engage through multiple blocks and get a more sophisticated understanding, through both integrating ideas from different disciplines and also expanding their knowledge and experience in upper level courses, we initiated the

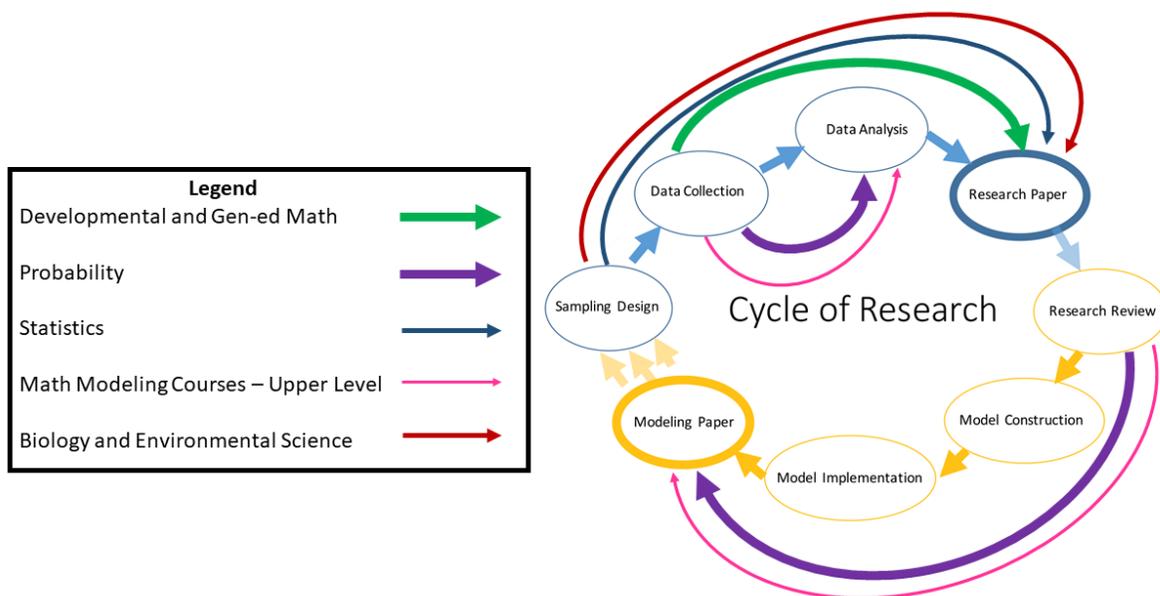


Figure 4 Class Coverage of the Cycle of Research

Note. Courses involved in the Hogsback project and how many steps of the cycle of research they cover. The arrows indicate the beginning and ending step with all steps in between covered by the course. At minimum, three steps in the cycle are covered in every course with six steps in a course being the maximum. The thickness of each arrow indicates the relative proportion of students that participate in the indicated courses. While the probability students cover the same steps in the research cycle as the math modeling courses, it is at an introductory level, where the modeling courses, which are upper level, get a more sophisticated experience of the cycle.

Hogsback project as a means of getting more students involved in STEM (science, technology, engineering and mathematics) fields by integrating science and mathematics. All classes have included at least three steps of the cycle of research with some classes including up to six steps (Figure 4).

The Hogsback Journal provided the HUB platform for student research papers and datasets that were accessible by all students involved in the project. Classes that collected data and checked for errors stored their curated datasets into the HUB. To date, hundreds of raw datasets and 30 curated datasets have been submitted to the journal.

Making *The Hogsback Journal* student run was a crucial step in the evolution of this project. Students that showed the necessary writing and editing skills were selected by professors involved in the project. Student editors were sent papers judged worthy of publication by professors in the appropriate field. Curated data sets were submitted to the journal by professors once their students finished verifying the data sets. Student editors did much of the work necessary to keep the process of publication running smoothly. In the Fall 2021 semester we had fifty submissions, in Spring 2022 semester we had fifty-nine submissions, and in the Fall 2022 semester we had fifty-six submissions. Editing these submissions engaged students in the cycle of science was good practice for students who had completed our scientific writing course and wished to be involved in the Hogsback project.

Classes involved in the project covered a wide variety of subject (Table 1) and produced a wide variety of student projects (Table 2). These projects resulted in diverse assemblage of student papers published in *The Hogsback Journal* (Table 3). Extracts from the results sections of student papers are included in Appendix A.

Table 1 A list of the courses involved in the Hogsback project

Environmental Science
Applied Environmental Physics
Soil Science
Sustainability
Biology and Ecology
General Ecology
Montana Wildlife and Habitats
Discover Biology
Mathematics and Statistics
Data Analysis and Modeling
Stochastic Modeling
Biostatistics
Probability
College Algebra
Intermediate Algebra
Geometry
Introductory Algebra

Given the range of classes involved in the Hogsback project, the array of projects conducted, the large number of datasets collected and curated, and the considerable number of student papers submitted to *The Hogsback Journal* in its first three semesters, the Hogsback project has been

more successful in generating student research than we ever imagined. We believe this success is due to the intense nature and productivity of the block system enabling the Hogsback research cycle to operate at block-accelerated speed.

Discussion of the Hogsback project

Participation in the Hogsback project exceeded all expectations in both the number of students and the professors that chose to be involved, the number of papers submitted to *The Hogsback Journal*, and the number of datasets collected and curated in *The Hogsback Journal*. What started with four professors expanded to twelve. Classes investigated a broad range of topics (Table 2).

Table 2 A sample of student projects done in the Hogsback project listed by topic.

Nest Architecture and Territory Size
Mound size surveys Mound age surveys Mound temperature profile surveys Mound steepness surveys Territory size surveys
Surveys of the Environment
Soil surveys Plant surveys Soil moisture studies Mound color differences related to temperature studies
Behavioral Observations
Foraging behavior assessment Transitions among behavioral traits Mound construction behavior Forager recruitment behavior Seed selection behavior Color preference in foragers Cooperative foraging behavior
Mathematical Modeling
Foraging models Behavioral transition models Effect of foraging on plant distribution and seed bank distribution model Territory size models Territorial conflict models Mound construction models Nest tunneling models Forager recruitment models Communication among activated ant models

As incoming freshman, students were introduced to the cycle of research and were provided with opportunities to get involved in a large-scale research project. As they advanced to higher level courses they acquired skills required to be able to conduct more sophisticated research. For many of their class projects students wrote scientific research or modeling papers. Because the Hogsback project was introduced through the existing structure of courses and class projects, the additional resources needed to implement the project were mainly for equipment to conduct specialized projects. We obtained funding through NASA (National Aeronautics and Space Administration)

in the form of a Montana Space Grant Consortium research activation grant and procured the additional equipment necessary to conduct projects that students were pursuing.

The project proved to be highly successful for three main reasons. First, we had excellent student engagement from the beginning which was supported by engaged professors who integrated the project goals into their existing courses. We had high output of student deliverables in terms of datasets and student papers which inspired new research questions. Second, the project drew expertise from students participating in a wide variety of classes. Third, the project created a Hogsback community of students connected through *The Hogsback Journal*. Students were excited to participate in classes involved in the project, to submit their papers and datasets to *The Hogsback Journal*, and to collect data at the Hogsback research site.

Table 3 Selection of titles of student papers published in *The Hogsback Journal*.

Select Paper Titles About Nest Architecture and Territory Size
“Linear relationship between surface temperature and mound steepness in the western harvester ant (<i>Pogonomyrmex occidentalis</i>)” “Territory size of the Hogsback western harvesting ant (<i>Pogonomyrmex occidentalis</i>) as a function of colony age” “Mound temperature as a response to mound color variation of the western harvester ant (<i>Pogonomyrmex occidentalis</i>)”
Select Paper Titles About Surveys of the Environment
“Biogeomorphology and soils of the Hogsback flat ecosystem” “Water absorption rates of mounds of the western harvester ant (<i>Pogonomyrmex occidentalis</i>)”
Select Paper Title About Behavioral Observations
“Do workers of <i>Pogonomyrmex occidentalis</i> (western harvester ant) display the same turning behavior when engaging in different jobs?”
Select Paper Titles About Mathematical Modeling
“Investigating mound building strategies of the western harvester ant (<i>Pogonomyrmex occidentalis</i>) through individual based stochastic three-dimensional behavioral modeling” “Individual-based stochastic model of the long-term effects of <i>Pogonomyrmex occidentalis</i> foraging on plant distributions and their seed banks” “Markov model of behavioral transitions in <i>Pogonomyrmex occidentalis</i> (western harvester ant)” “Do the Hogsback western harvester ants (<i>Pogonomyrmex occidentalis</i>) follow an optimal foraging pattern?”

We learned that this type of project was easy to implement and integrate into the fast pace of the block. It required only a few professors willing to engage students in the cycle of research by producing research papers, modeling papers, and datasets. As time progressed student participation grew and more classes were added to the course mix of the Hogsback project. *The Hogsback Journal* was crucial for providing the hub of connectivity necessary for sharing information across disciplines. Each new research finding generated new research questions causing the project to evolve. For example, in the first semester students deconstructed mounds and identified what materials were used in their construction: fine gravel mixed with silty loam and a small amount of vegetation clippings. This encouraged a surficial processes course to determine that the majority of fine gravel was collected by the ants from the surrounding area. This information led students to become interested in how the returning workers affect the angle of the mounds by their placement of gravel loads. This led to testing the mound mixture and components to find the maximum possible mound angle before the mound crumbled. A calculus course determined the coefficient of friction for the gravel and began preliminary modeling of mound crumbling. A

student in an upper-level stochastic modeling course was able to use all of the papers written by students in the previous courses to construct a stochastic individual-based model of mound construction that incorporated foragers placing gravel on the mound and the mound crumbling over a series of years to produce model of how the mound develops over its first five years. The angle of their mound is important for this species as steeper mounds collect more solar radiation thereby warming the mound more quickly.

This research tied into another line of research involving solar heating of mounds due to their slopes receiving more direct sunlight and made predictions of mound temperatures. At the heart of this project was *The Hogsback Journal*, which gave one location for all of the previous papers written about mound construction and solar heating.

The Hogsback project provides a model for conducting multidisciplinary research on the block. We have used this structure to implement multidisciplinary research incorporating statistics and exercise physiology courses. We propose a general structure for implementing this type of research on the block which we call HUB research.

Implementation of HUB research projects

In Table 4 we list some of the challenges that should be considered when undertaking interdisciplinary cooperation on the block. Each of these challenges must be carefully considered before initiating any multidisciplinary research program.

There are many challenges involved in implementing the cooperation necessary for initiating multidisciplinary research projects (Table 4). We considered plans that involved a reorganization of existing course offerings, course rotations (Hanson & Stultz, 2022), and departmental alignments (Creso, 2008), but decided on a simple plan that: (1) could be implemented immediately; (2) involved no reorganization of existing course offerings, course rotations, or departmental alignments; and (3) that required only a small group of faculty members to implement. The research plan we implemented worked within the existing block schedule, existing assessment framework, did not require extra student or faculty time, minimized coordination time among faculty, and was flexible enough to evolve through inquiry-based research.

We outline a simple and efficient approach to implementing multidisciplinary research that we call HUB research. We call it HUB research because we connect students across disciplines through a repository for student papers and data. As *The Hogsback Journal* serves as the HUB platform for the Hogsback project making student papers and data accessible to all students participating in the research. The HUB research cycle is initiated by connecting with a colleague in a different discipline (Figure 5). Initiating a HUB research program involves aligning existing components in courses with the HUB research cycle. This avoids requiring additional time for students and professors and allows each course to use the assessment methods already in place. Scheduling is not an issue as the HUB research in each class can be conducted asynchronously.

Table 4 The Challenges of Interdisciplinary Cooperation

<p>Assessment. Courses in different disciplines are required to meet different objectives. Often, disciplines must meet standards required by different accreditation agencies.</p>
<p>Scheduling. While block scheduling provides extremely efficient scheduling within disciplines, it is difficult to integrate schedules across multiple disciplines. In addition, constructing a schedule that provides students with repeated interdisciplinary experiences through their progress from freshman to senior across multiple disciplines is a complex timetabling issue (if not intractable).</p>
<p>Student time. Block scheduling was designed to provide students with the time they need to master one subject at a time without distraction. Time theft (multiple professors competing for a student’s intellectual attention) is exactly what the originators of the block schedule at Colorado College wanted to solve (Loevy, 1999; Taylor, 1999). Re-introducing time theft violates the purpose of the block scheduling.</p>
<p>Faculty time: For faculty, our focus must be on the students in our course. Attending meetings and conducting other faculty duties leaves faculty with little extra time to engage in interdisciplinary activities.</p>
<p>Coordination time: The Law of Professorial Interaction states that <i>the time it takes to make a coordinated decision increases exponentially as the number of professors involved</i>. Minimizing coordination time is essential for maintaining efficiency on the block and engaging in interdisciplinary activities.</p>
<p>Lack of administrative support. While most administrators recognize and support the importance of cooperation across disciplines, some administrators do not.</p>

Note: Regarding the Law of Professional Interaction. In 2018, after determining in the field that the time it takes for foraging ants (of the species *Pogonomyrmex occidentalis*) to transport a large food item to their nest increases exponentially as the number of ants involved, J. Dyreson (aged 13) immediately proposed this corollary for professors.

The HUB research cycle is connected through the formal output of students in each class and should generate a cycle of inquiry-based questions and answers much like *The Hogsback Journal* did for the Hogsback project. This direct connection between students through their formal outputs is what drives the cycle of research into new areas. The formal output of each class is made available to all students by establishing a HUB platform for sharing research output. The five simple steps involved in initiating a HUB research project are outlined in Figure 5. Specific examples of initiating HUB research projects are provided in Figures 6 & 7.

The following section will discuss, in more detail, how the HUB research project will evolve.

Evolution of HUB projects

When initiating a HUB research project it is important to consider the evolution of the project over time. Other courses should be encouraged to join the project. This offers students the opportunity for block stacking in which students to engage in multiple blocks of HUB research throughout their career. The more classes engaged in the project, the more opportunities there are for repeated research in different parts of the research cycle. Both, lower and upper division courses should be encouraged to join. Lower division courses offer students an introduction to interdisciplinary research while upper division courses offer opportunities for more sophisticated research experiences.

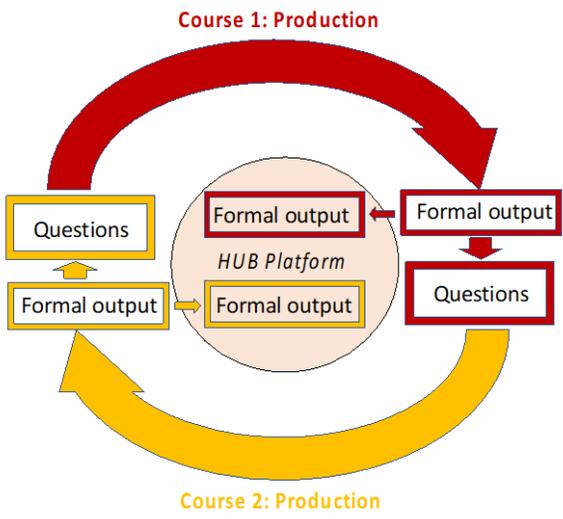
<p>1] Connect with a professor in another discipline over tea and chat about your classes.</p>	
<p>2] Ask your colleague, "What do you do in your class that would inform the students in my class?" "What questions can your students generate that my students can answer?" Answer the same question for your colleague.</p>	
<p>3] Use the answers to these questions to create a HUB research cycle. Decide what the formal output from each class will be and create the HUB platform where you exchange ideas between classes.</p>	
<p>4] Align class assignments to implement a HUB research project. Each professor should choose an experiential component integral to their class in which their students produce the desired formal output for their part of the cycle. Each of these components should meet the requirements (objectives, assessment outcomes, etc.) for the respective course.</p>	
<p>5] Establish a <i>HUB platform</i> accessible to all students and faculty involved in the HUB research project. The <i>HUB platform</i> serves as a repository for formal output that connects students across the research cycle generating the questions and answers that drive the cycle.</p>	

Figure 5 Steps in Implementing a HUB Research Program research cycle. Each discipline generates questions for the other discipline driving the research

As the project evolves, the HUB platform of research papers, dataset, prototypes, and designs, will grow, providing participants with a valuable resource that will generate new ideas and research

Note: Left: Steps for initiating a HUB research program. Right: Conceptual diagram of the HUB cycle. The formal output produced by each class is archived and disseminated through the HUB Platform.

questions. As the project evolves, HUB participants will form a new student/faculty community that encourages collaboration across disciplines and engagement in the HUB cycle of research. This engagement will lead to additional growth of the HUB project.

Since the HUB research project is embedded in a form of compressed scheduling that avails of an intensive mode of teaching, namely the block, the following paragraphs will discuss the power of the block in the context of HUB research.

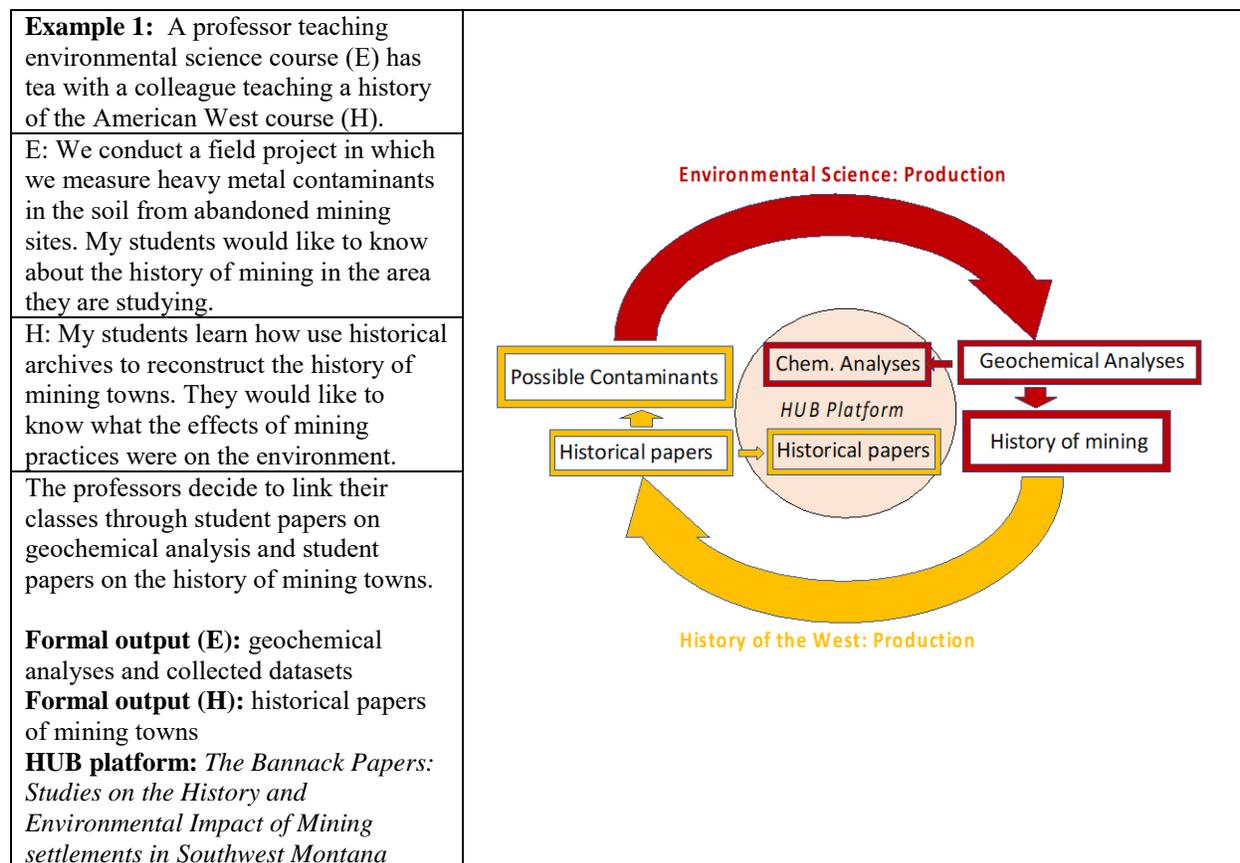


Figure 6 Example 1: Implementing the HUB Research Program

Note: Left: Example of initiating a HUB research program connecting environmental science and history. Right: Conceptual diagram of the HUB research cycle. Each discipline generates questions for the other discipline driving the research cycle. The formal output produced by each class is archived and disseminated through the HUB Platform.

The power of the block in HUB research

The power of the block is its focus (Sheldon & Durdella, 2009; Anderson & Anderson, 2012). The University of Montana Western block is three and a half weeks with 18 instructional days and 3 hours per day. In a single semester on the block students may progress through a sequence of courses that would take years to complete on a semester schedule. A HUB research project amplifies the power of the block when it includes multiple courses across multiple disciplines. Imagine a student takes three courses in a semester involved in HUB research. In their first class on soil science the student collects data, in their second class on statistics the student analyzes the data, and in their third course the student builds mathematical models based on the analyses of the data collected earlier in the semester.

Typically, it would take two to three semesters of coursework for a student to become proficient in all these steps. On the block, a student can complete all three of these courses in one semester. Intellectual progress occurs at block-accelerated speed, increasing the capabilities of students to conduct research and the amount of research students can accomplish. As students contribute (as

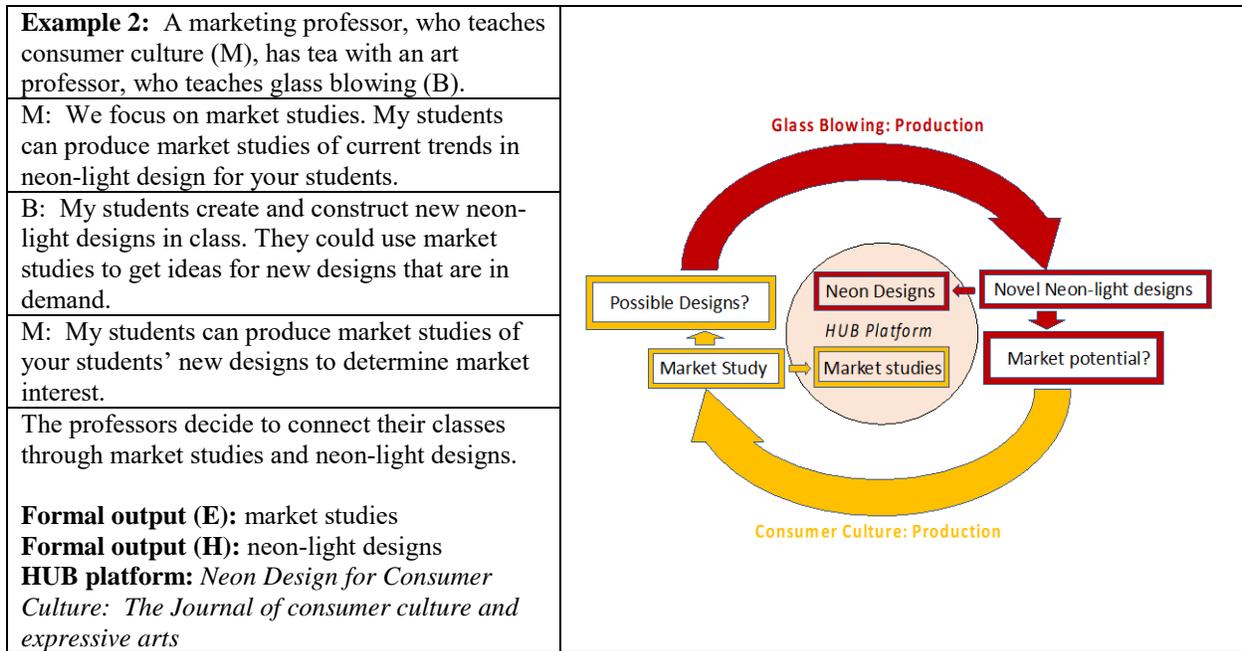


Figure 7 Example 2: Implementing the HUB Research Program

Note: Left: Example of initiating a HUB research program connecting business and art.

Right: Conceptual diagram of the HUB research cycle. Each discipline generates questions for the other discipline driving the research cycle. The formal output produced by each class is archived and disseminated through the HUB Platform.

individuals or small groups) formal output to the HUB platform each block, this resource grows at an astonishing rate.

In addition to encouraging multidisciplinary cooperation, HUB research projects are a viable and extremely productive inquiry-based model for research in general. HUB research projects proceed at block-accelerated speed. As formal output is immediately accessible on the HUB platform to all participants, students are able to engage in inquiry-based research using the latest results. The formal output of each block informs the next, and the more classes are involved, the more the pace increases, with students accomplishing more research (and more sophisticated research) in shorter and shorter periods. HUB research provides a new model for the pursuit of research. New research models often result in more progress than one might imagine (Flexner, 1939).

Another advantage of HUB research is its natural inclusivity. HUB research provides students with a welcoming and inclusive experience as part of an entry level course and a natural progression of research experiences that accompany increasing expertise acquired in subsequent courses. Students do not have to wait until their junior or senior year to engage in research, to play work-ups in a laboratory washing bottles in the hope of eventually conducting research, to compete for the few student research positions available, to be assigned research tasks for which they are not intellectually prepared, or to feel outside their natural comfort zone and outside their community

of friends. Instead, HUB research engages students as a natural part of their course of study in the context of their community of classmates. As part of their intellectual development, students make the transition to become researchers.

When engaging students in HUB research the first step is always to acquaint students with the cycle of research being pursued (for example, see *Figure 1*). Students enjoy engaging in HUB research in large part because their contribution to this shared endeavor will help other students answer research questions that go far beyond data collection in a particular class. Engaging students early in the HUB research cycle prepares students for future engagement in other parts of cycle of research.

Conclusion

In summary, as we show in the Hogsback project, HUB research projects provide multiple advantages to programs on the block schedule (*Table 5*). The HUB research cycle amplifies the power of the block so that HUB projects proceed at block-accelerated speed because students can participate in multiple successive classes focused on the HUB project, like the students were able to in the Hogsback project. As it evolves, a HUB research project will encourage more multidisciplinary cooperation through inquiry-based research as the project requires expertise from more disciplines.

HUB research projects provide a simple way to implement interdisciplinary research on the block. This approach avoids the challenges inherent in interdisciplinary research (*Table 4*), provides multiple benefits for students and faculty (*Table 5*), and sets up conditions that allow for the rapid evolution of HUB research projects as more students and faculty join in the HUB research cycle.

By providing readers with a rationale for launching a HUB research project and a simple approach for implementing such a project that avoids common challenges to interdisciplinary cooperation, we hope to encourage readers to engage in multidisciplinary collaborative efforts. Like the Hogsback project, the HUB approach is designed to be implemented quite simply by engaging a colleague in a thoughtful discussion over tea about how each discipline can inform the other.

Table 5 The Advantages of HUB Research

Is simple to implement
Encourages multidisciplinary cooperation
Establishes long-term research programs that evolve
Is naturally inclusive for students
Establishes a pathway for students to become researchers
Is production driven and experiential
Allows for block stacking
Is a powerful tool for research

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Disclosures

No conflicts of interest, financial or otherwise, are declared by the authors.

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Appendix

Appendix A: Extracts from student papers published in *The Hogsback Journal*

The following extract is the results from “Biogeomorphology and soils of the Hogsback Flat ecosystem” (*Table 2*).

Results

The soil profile consisted of three horizons. These horizons can be seen in Figure 2 and an image of a violently effervescent reaction can be seen in Figure 3. The gravel clasts that are greater than 4.00 mm for each horizon can be seen in Figure 4 with Horizon #1 possessing the largest clasts and Horizon #3 possessing the smallest clast.

Figure 2. Soil profile at edge of inactive Ant mound exhibiting 3 horizons. Horizon #1 is a silty loam of 10YR 6/3 color and a 7% gravel composition from depths 30-37cm. Horizon #2 is a Clay Loam of 10YR 7/3 color and a 8% gravel composition from depths 20-30cm. Horizon #3 is a Clay Loam of 10YR 6/3 color with a 17% gravel composition.



Figure 3. Violently Effervescent (VE) reaction of HCl and CaCO₃.



Figure 4. >4.00 mm fraction of grains within soil profile.

Beginning from the bottom, Horizon #1 ranged from thirty to thirty-seven cm deep with a color of 10YR 6/3. It had a silty loam texture with 7% gravel content made up of subrounded one-cm quartz and granite. It experienced a

violently effervescent reaction to HCl, indicating a large CaCO₃ presence. Horizon #1 was not cemented with CaCO₃, but commonly coated grains. Sieving revealed that 58% of the mass has a 500-63µm grain size and 15% at the 2mm-500µm grain size. Data for Horizon #1 is recorded in Table 1.

Table 1. Horizon #1 Description.

Horizon #1			
Characteristics		Sieving	
Depth (cm)	30-37	Sieve	Mass (g) % Compostition
color	10YR 6/3	>4.00mm	2.0 6%
Texture	Silty Loam	4-2mm	2.0 6%
% Gravel	7%	2mm-500um	5.0 15%
Gravel Composition	Quartz	500-63um	19.0 58%
Structure	Subrounded 1cm	<63um	4.6 14%
CaCO ₃	VE	Total:	32.6 99%
Notes	CaCO ₃ coating on clasts, horizon not cemented, common grain coatings		

Horizon #2 sat between depths twenty to thirty cm with a 10YR 7/3 color. Its texture was a clay loam with 8% gravel content with mostly sub angular structures. It was a cemented horizon with violently effervescent reaction to HCl. Sieving showed that the majority of grain sizes were smaller than 2mm with 70% in the 500-630 µm fraction, 14% in the <63µm fraction and 12% of the mass in the 22mm-500µm fraction. The heavily cemented horizon also held ant burrows as seen in Figure 5. Data for Horizon #2 is recorded in Table 2.



Figure 5. Ant tunnel within Horizon #2 of soil profile as evidence of sub surface bioturbation.

The following are the results from “Territory size of the Hogsback western harvesting ant (*Pogonomyrmex occidentalis*) as a function of colony age” (Table 2).

Results

A one-way ANOVA test was conducted, and it was found that age was a significant factor in the distance between ant mounds ($F_{2,15}=16.1974$; $p= 0.000179$). Age of the mound accounted for 68.3% of the variation in distance to the nearest mound. The age of the ant colony appears to have a significant effect on territory size (Table 1).

Table 1: Table one shows the one-way ANOVA test that was conducted at a significance level of 0.05.

One way ANOVA Table.

Source	SS	df	MS	F	Prob>F
Age	374.0897	2	187.0449	16.1974	0.00179*
Error	173.2175	15	11.5478		
Total	547.3073	17			

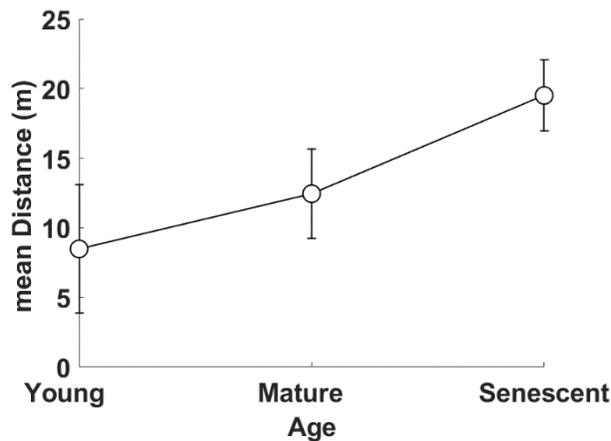


Figure 1: Graph of the mean distance of the nearest mound for young, mature, and senescent mounds. Error bars represent 95% confidence intervals.

Table 2: The results of post-hoc tests for density showing p-values for two-sample t-tests assessed at the Bonferroni corrected level of significance (0.0167). The mean distance to the nearest mound for young mounds was significantly lower than that of senescent mounds. Similarly, the mean distance to the next mound for mature mounds were significantly lower than senescent mounds.

	Senescent	Mature
Young	0.000317*	0.099756 n.s.
Mature	0.001282*	

*Significant factor

n.s. Not significant

The following are the results from “Do the Hogsback western harvester ants (*Pogonomyrmex occidentalis*) follow an optimal foraging pattern?” (Table 2).

Results

Figure 3 shows the Markov matrixes in the form of bar graphs for the empirical data that was collected on the date of 9/24/21. **Figure 4** shows the optimal movement of ants for an average of thirty days. **Table 1** shows the Markov transition matrices for Figure 4. The empirical data from 9/24/21 shows that the ants would have only covered around 14.7 square meters, covering 23% of their territory with an over coverage of 9% and their average product being 49.94%. In comparison, the optimal data shows that if

the ants were to perform in this way, they will have covered 29% with an over coverage of 9% but with an average product of 74.47%.

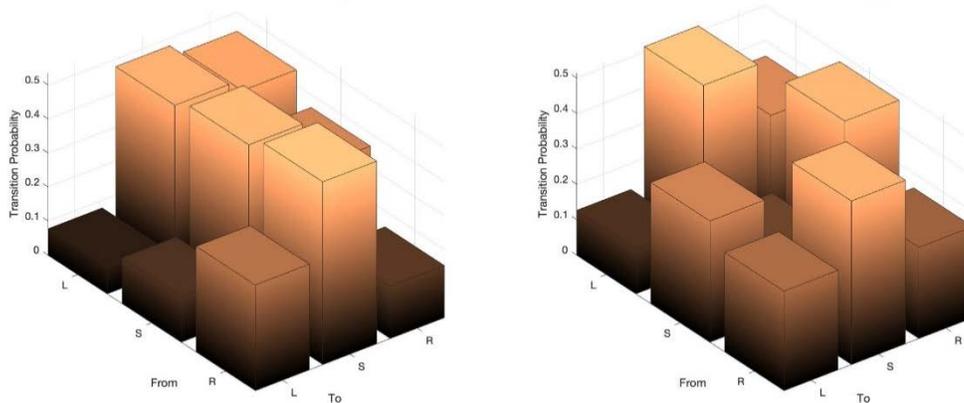


Figure 3. Bar graph showing the pattern of foraging by *P. occidentalis* modeled using Markov transition matrices calculated from data collected by students on September 4, 2021. The model displays the probability of the possible movements that an ant could make. The left bar graph shows the transitions near the mound and the right (~1m), the transitions far from the mound (~3m)

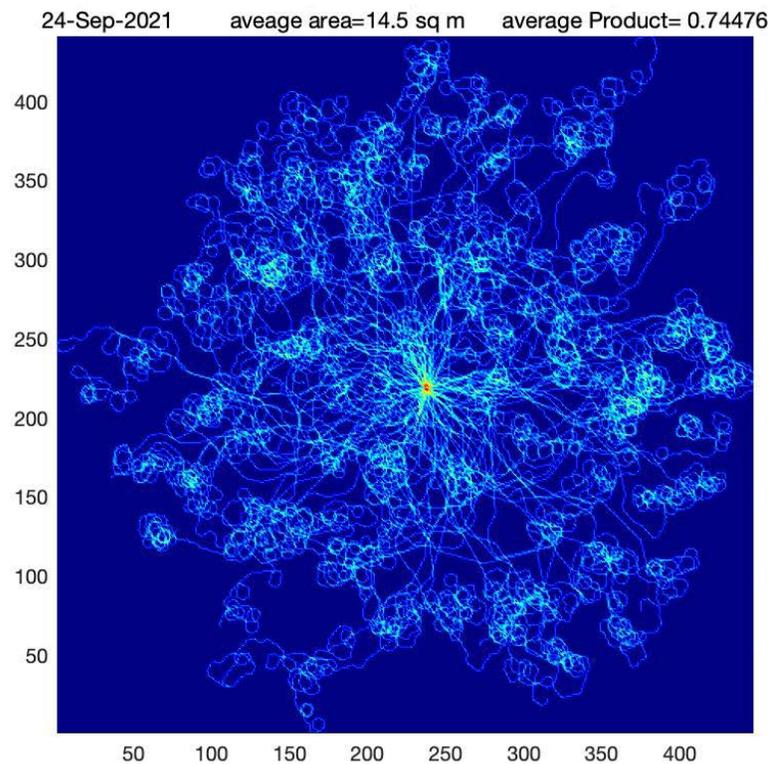


Figure 4. Plot showing the pattern of the OPTIMAL foraging by *P. occidentalis* modeled using Markov transition matrices calculated from data collected on October 13, 2021. Foraging trails begin at the nest and radiate outward. The model was averaged over thirty days giving an average coverage of 29% (all trails); an average over coverage of 9% (lighter colors); and an average area explored of 14.5 square meters. And an average product of .7447.