WORCESTER POLYTECHNIC INSTITUTE

CREATING LESSON PLANS

To Teach Students About The Environment At The Hubbard Brook Experimental Forest

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THIS PROJECT IS AN INTERACTIVE QUALIFYING PROJECT (IQP) SUBMITTED TO THE FACULTY OF WORCESTER POLYTECHNIC INSTITUTE LOCATED IN WORCESTER, MASSACHUSETTS, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE.

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Abstract

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The Hubbard Brook Research Foundation (HBRF), based in the White Mountain National Forest of New Hampshire, offers a K-12 education program to support student learning in environmental science, earth science, and STEM inquiry. We designed four lesson plans for the HBRF about water quality, tree health, the food web, and phenology. We created and refined the lesson plans through surveys, literature review, seven interviews, and six pilot tests. The lessons emphasize hands-on, outdoor activities to increase student interest in nature. In these lessons, students act as scientists with some competitive aspects to boost engagement. Long-term, the knowledge students gain from the lesson plans will hopefully inspire them to be more environmentally conscious.

Acknowledgements

We thank the public school teachers we interviewed: Melissa Jellison, high school teacher at Lisbon Regional School; Leslie Houghton, middle school teacher at Lisbon Regional School; Jen Weatherbee, teacher at Plymouth Middle School; Rose Dedam, high school science teacher at St. Johnsbury Academy.

We thank the teacher whose students we piloted lessons with: Rebecca Steves, middle school science teacher at Lin-Wood Regional School.

We thank environmental education organization employees whom we interviewed: Kayla Croteau, Watershed Education Specialist at NH Fish & Game; Stuart Hickey, Coos County Education Coordinator at the AMC; Amanda Carron, Associate Director of Programs at White Mountain Science Inc.

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Background

Remember being young, when the fireflies flashing their lights drew you outside almost every night? Besides outdoor enthusiasts, many people have lost connection with nature. According to Yale, Americans spend on average less than five hours each week in nature (Yale, 2017). Such limited time in nature may be why so many people show disregard for the environment, only adding onto the growing messes that threaten the environment. So join us as we explain how we will stir up passion for the natural world, starting with the next generation, and get them learning about the outside in the outside.

We begin this section by exploring the environmental issues wreaking havoc on forests in the Northeast of the United States. To mitigate environmental issues, environmental education is necessary to ensure that people are aware of their effect on the environment. The educational methods we focus on are outdoor lessons, experiential learning, and partnerships with scientific sources. Finally, we introduce our sponsor organization, the Hubbard Brook Research Foundation, an organization that provides scientific outreach and environmental education.

1. ENVIRONMENTAL ISSUES

Unfortunately, many issues plague forests, ranging from deforestation, invasive species like the emerald ash borer, to natural disasters like ice storms. The destruction of trees interferes with a forest's complex ecosystem. Satellite imaging of New England's forests has shown a consistent decrease in overall forest area since 1985. The shrinking forest area can be seen in Figure 1.

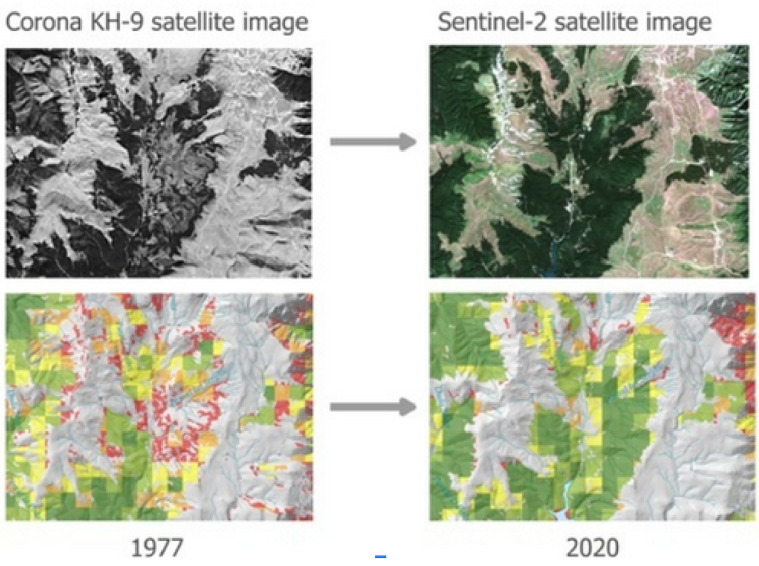


Figure 1: Forest fragmentation over time (Bogdan Olariu et all, 2022)

An estimated 955,450 acres of forest were cut down between 1985 and 2016, with little forest expansion to offset the losses (Olofsson et al., 2016). This shrinking leads to multiple negative outcomes, like carbon imbalances in the atmosphere and loss of habitat for many species. Environmental analysts at the University of Vermont have modeled the effects of deforestation in New England using historical data. They project that by 2075 New England will have a six percent reduction in overall forest coverage (Cadenasso & Pickett, 2008).

Moreover, fragmentation, the process by which a contiguous forest is broken up into smaller unconnected plots, has increased drastically between 1977 and 2020. Each colored box in Figure 1 shows an area of fragmented forest coverage. An increase in forest fragmentation directly correlates with a loss in biodiversity and an increased vulnerability to invasive species (Adams et al., 2019). For example, the invasive emerald ash borer is responsible for the deaths of millions of trees and causes nearly $1.7 billion in local government spending a year (Aukema et al., 2011; Larson et al., 2023). When a new species is introduced, it can have harmful effects on the complex ecosystem.

As climate change worsens, extreme weather events grow more severe. Ice storms especially affect many forests in colder regions such as the northeastern U.S., including the White Mountain National Forest (Hubbard Brook, 2020). Ice storms are not fully understood and they can have long-lasting and devastating effects on forests. For example, many forests in New England have not yet recovered from the Ice Storm of 1998; this damaged their tree canopies, root systems, and nitrogen levels (Hubbard Brook, 2020). The impact of an ice storm on trees can be seen in Figure 2, as a student researcher measures ice accretion on trees during an ice storm. Additionally, ice storms pose a threat to electrical and communication systems and to people's homes, which can lead to extensive repair costs (Degaetano, 2000).

Background

Figure 2: Artificial ice storm at the Hubbard Brook Experimental Forest (Klementovich, 2017)

Climate change is a significant threat to forests as well. Forests do not handle a change in climate well due to larger trees being slow to adapt to changes in their environment. This means that when carbon dioxide levels in the atmosphere increase, there is a corresponding increase in rates of photosynthesis in trees, however this presents a major issue to forest health when there isn't also an increase in access to nutrients (Ainsworth & Long, 2005).

2. EDUCATING STUDENTS ON THE ENVIRONMENT

Environmental education is a necessary process for addressing environmental issues. Educating children is especially important because what students learn when they are young will affect the path they take for their future studies and careers. If children are taught about nature, they may bring that new perspective with them as they make choices in the future (Peterson, K. 2022). Below we discuss three approaches to education: outdoor lessons, experiential learning, and learning through partnerships between students and scientific organizations.

The most common approach, traditional learning, is not effective on its own. Teachers should be wary of lecturing for too long because studies have found ten to fifteen minutes to be the maximum time a lecture can last before significant decreases in both attention and retention begin (Ariga & Lleras, 2011).

Traditional methods like lecturing and handouts are viable supplements to hands-on lessons and outdoor activities. By using interactive lectures, students who typically had poor performance on academic evaluations can perform similarly to students with ample prior understanding (Ernst & Colthorpe, 2007). The study found that a range of methods should be used in tandem to ensure that students with differing abilities and preferences can reach full understanding.

2.1 Outdoor Lessons

Hosting lessons and activities outdoors has positive effects on students' emotional health, creative development, ecological knowledge, and social skills. Researchers from the Environmental Science Agency carried out an experiment by having students participate in nearly identical lessons but with different surroundings. After only a week, students who were taught outdoors showed higher satisfaction for their basic needs, motivation, engagement, and joy in learning than those who were taught indoors (National Environmental Education Foundation, 2022). There were similar findings in a study of six preschools, four test and two control schools, where students performed activities in natural settings, focusing on holistic development. Students at the four outdoor-based preschools outperformed the two indoor preschools in an executive functions assessment (North American Association for Environmental Education, n.d.). Holding discussions outside can also have benefits, like the outdoor discussion seen in Figure 3.

Figure 3: Brendan Leonardi outdoor teaching (HBRF staff, Sep 2021)

In another study, the Preservice Early Childhood Teachers group incorporated nature trails into their lessons. Their lesson plan included lectures, seminars, workshops, and outdoor experiential learning for preschool to third-grade students. Students reported higher interest levels and showed excitement when learning on the experiential trails compared to learning the same content in a classroom (Lee & Ensel, 2019). Using five trails, students engaged in journaling, finding insects, and other activities that achieved the learning outcomes. The benefits of outdoor lessons are compounded with the use of experiential learning.

2.2 Experiential Learning

Whether it is using blocks to demonstrate mathematical operations, or growing plants to see how the greenhouse effect works, students have more fun when they are involved in experiential learning. Experiential learning is a method of learning through direct experiences (Gross & Rotland, 2017).

The Project Learning Tree (PLT) has many programs for teaching students about the environment through activities or experiential learning. In Figure 4, young students can be seen catching wildlife in a stream while learning about organisms that live in streams.

Figure 4: Young students catching animals while learning about biology (The Project Learning Tree, 2023)

For example, PLT has used games to engage students and instill information. One PLT lesson really stands out. Teachers assign students specific animals by giving them a name tag and gathering the students into a circle. Students then describe their assigned animal's relation in the food web to another student's assigned animal. After which they toss a ball of yarn to that student, creating a physical web of yarn to represent the food web (Reynandez, 2019). In another example at the Delta Preserve, a secondary education field trip was conducted, where students would rotate through three stations, each one using a different experiential teaching method (Jose, 2017). One of the surprising activities that proved effective at helping students learn was doodling. Students could conceptualize new information, like the anatomy of an animal, and better understand it. By comparing assessments before and after the field trip, overall performance was notably higher (Jose, 2017). Boaler found by comparing secondary schools, the mathematical achievements of the school using experiential learning exceeded the school using traditional learning (David, 2008; Law Insider, n.d.). Admittedly, this method takes more time to teach the same material than traditional teaching methods. However, these outdoor lessons will have a positive impact in many areas of life for students, as we quote the National Environmental Education Foundation in Figure 5.

Students that were taught outdoors showed higher satisfaction for their basic needs, motivation, engagement, and joy in learning than those that were taught indoors

Figure 5. (National Environmental Education Foundation, 2022)

2.3 Scientific Sources and Partnerships

Partnerships between schools and scientific organizations can help often under-resourced teachers impact more students. Through these partnerships, students gain more scientific knowledge and skills than would result from a traditional class (Bopardikar et al., 2023). These partnerships have also benefited teachers by improving their teaching methods. For example, scientists can suggest modifications of classroom lessons to be more in line with new scientific discoveries or to give students a connection to other fields of science.

Background

Additionally, through these partnerships, scientists gain valuable insight into public schools and scientific outreach (Bopardikar et al., 2021). Sometimes, college students can fill the scientific organization's role in teaching. Interacting with college students can make middle and high school students more invested in a topic. Mentorship from a qualified educator has been proven to have a positive impact on students' level of investment in STEM topics, even more so when the mentor is close in age to the student (Aloisio et al., 2022). Examples of university-school mentor/mentee relationships report “high anticipation among their students for the visits by university scientists”, demonstrating the ability of these relationships to create interest in STEM learning (Rollwagen-Bollens et al., 2019).

A valuable scientific resource for educators is the Next Generation Science Standards (NGSS), a set of research-based standards for scientific knowledge and understanding for students K-12 with the goal of giving teachers the flexibility to design their curriculum based on their own classroom. These standards give valuable insight into what is important for each age group to learn and the methods used for each topic. The standards were developed to increase the number of students entering STEM fields (Next Generation Science Standards, n.d.). Resources like the NGSS and partnerships with scientific organizations are highly valuable for educators to help design lessons.

3. HUBBARD BROOK

The Hubbard Brook Research Foundation (HBRF) is a nonprofit organization established in 1993 located within the White Mountain National Forest in New Hampshire. However, research first began within the White Mountain National Forest at the Hubbard Brook Experimental Forest (HBEF) in 1955. All 7,800 acres of the HBEF are shown on the map in Figure 6, with labeled lakes and mountains. The HBRF utilizes research in the Experimental Forest to educate students, inform policy-makers, aid scientists, and provide datasets to the public and to teachers.

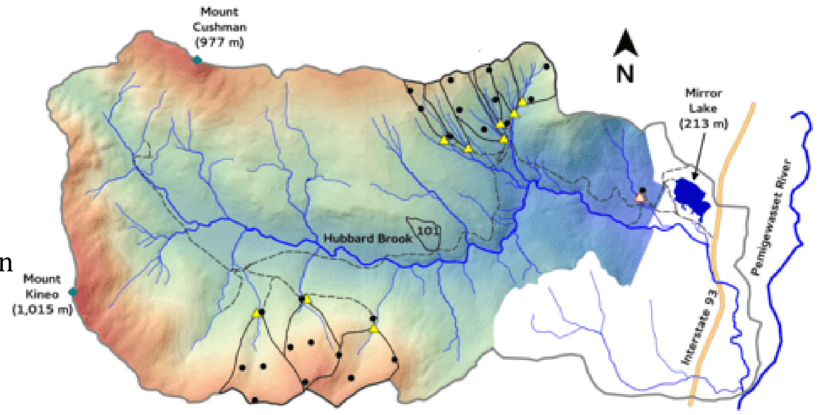


Figure 6: The Hubbard Brook Experimental Forest and its Hydrometeorological Stations (Campbell, 2010)

The HBRF's work to promote research conducted at the Experimental Forest has had a profound impact on emissions policy and the conservation of forests. The HBRF shares data with politicians in environmental decision-making roles to influence policy-making, like in discussions about the 100% Clean Economy Act, the Great American Outdoors Act, the Moving Forward Act, and in hearings of the House Agriculture and Energy and Commerce Committees (Hubbard Brook, n.d.). Part of their research includes measuring water flow, which is captured in watersheds, as seen in Figure 7.

Figure 7: Watershed 4 in the Hubbard Brook Experimental Forest (Aiden Johnson, Sep 2023)

Background

Along with supporting and sharing research, the HBRF offers a K-12 education program to promote student learning in environmental science, earth science, and STEM inquiry. They offer tours of the Hubbard Brook Experimental Forest to expose students to the research being done there. During tours, students learn more about real research, cutting-edge experiments, and long-term monitoring sites like the HBEF's watersheds.

To extend their education program's reach, the HBRF planned to set up a research plot in the Experimental Forest to bring students after their tour. Students conduct activities in these research plots that allow them to engage with the forest, collect environmental data of their own, and gain a better understanding of how and why forest research is conducted. We worked in collaboration with our sponsor, Brendan Leonardi, the Young Voices of Science and Education Manager at the HBRF (pictured in Figure 8), to develop lesson plans to help inspire student curiosity and interest in science.

Figure 8. Brendan Leonardi (Klementovich 2023)

Methodology

The goal of our project, sponsored by the Hubbard Brook Research Foundation, was to design engaging lesson plans for 6th-12th grade students visiting the Hubbard Brook Experimental Forest about forest ecology and inspire curiosity for nature and science. In order to accomplish this goal, we completed the following objectives:

O1: Assess HBRF's approach to education

O2: Investigate other approaches for developing science and nature lessons

O3: Draft and pilot lesson plans

O4: Finalize deliverables

We outline the objectives in the flowchart in Figure 9.

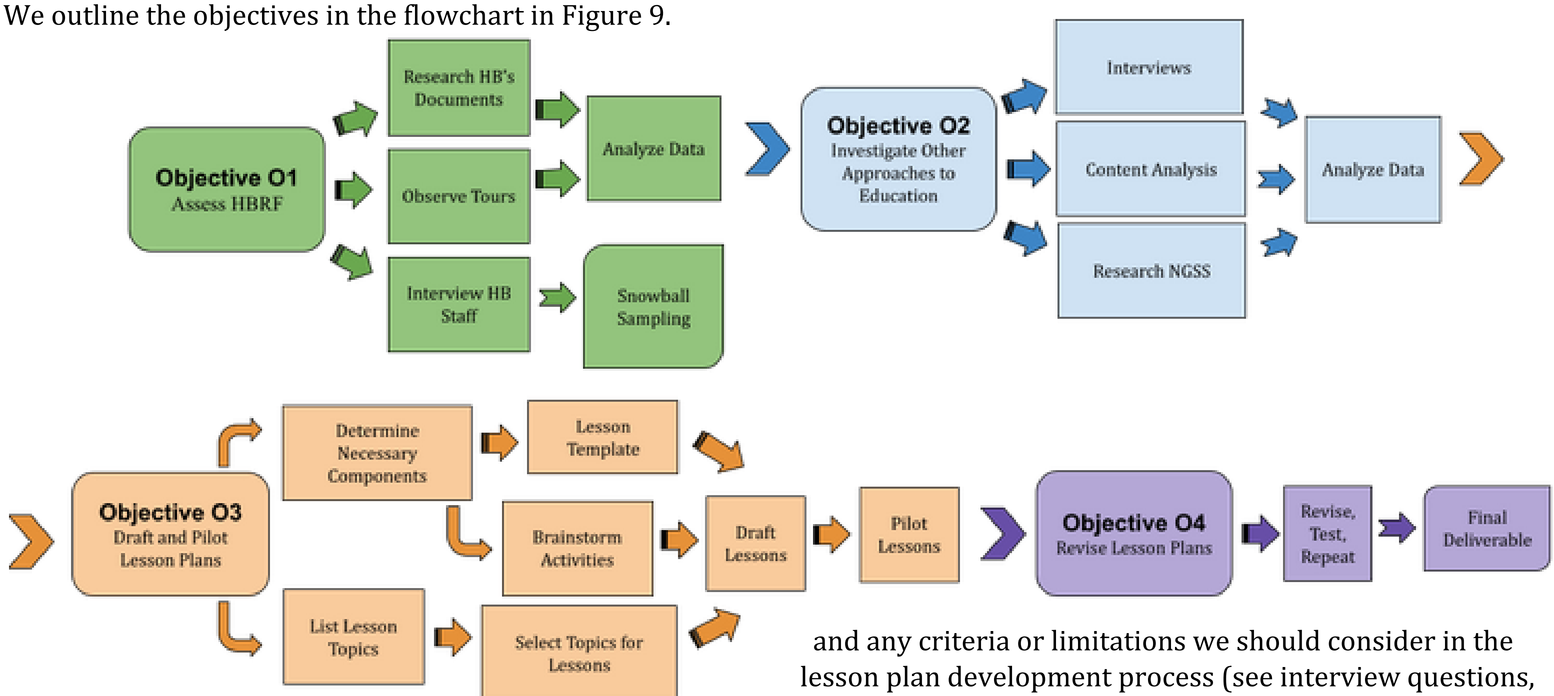


Figure 9: Project objectives flowchart

O1: Assess HBRF's Approach to Education

To begin, we learned about Hubbard Brook's methods for educating primary and secondary school students. To achieve this objective, we analyzed the HBRF's existing materials, facilitated a focus group, conducted interviews, and observed lesson tours.

First, we analyzed the content of the educational information available on the HBRF's website. We collected information about the locations and tour stops within the Experimental Forest, the resources and handouts HBRF staff provide to each tour group, available data lessons on the Hubbard Brook website, and their watershed program. We asked our sponsor, Mr. Leonardi, to give us a tour through the Hubbard Brook Experimental Forest, observing what the average student experience would be.

SWe interviewed Mr. Leonardi and asked about his experience with the HBRF's lesson plan development and implementation, and any criteria or limitations we should consider in the lesson plan development process (see interview questions, Appendix C.3). We define a lesson plan as the model for facilitating a lesson; including the goal of what students should learn, the procedure to achieve that goal, required resources, and a way to evaluate how successfully the goal was achieved (FutureLearn, n.d.). Mr. Leonardi was an excellent resource considering he has given 61 tours during his 4 years as an educator at the HBEF, with an additional 2 years of work as a Field Technician. Additionally, Mr. Leonardi connected us with his coworkers, Amey Bailey and Hannah Vollmer, technicians from the U.S. Forest Service, who are involved with education. We facilitated a joint interview with two Hubbard Brook staff (see Hubbard Brook staff questions, Appendix C.2).

In addition to interviews, we conducted systematic and participant observations of Hubbard Brook's lesson plan delivery, specifically tours and interactive activities following tours. We performed systematic observation, the collection of data using a rubric, which set parameters of what we wanted to record and where to record it (Given, 2008), of Hubbard Brook's student tours (see systematic observation consent, Appendix E.5). We took detailed notes of both how Hubbard Brook staff operate tours and deliver lessons and how they interact with students and teachers. We expected systematic observation to be effective on student tours because it did not rely on subjective feedback, and had minimal influence on student behavior. Additionally, we held a debrief with WPI students after the activities to obtain feedback about the lesson plans (see pilot lesson plan consent, Appendix F.3 and F.5).

O2: Investigate Other Approaches and Factors for Developing Science and Nature Lessons

Hubbard Brook staff put us in contact with environmental educators and public school teachers, whom we interviewed. This process of identifying new interviewees with the help of previous interviews is called snowball sampling (Given, 2008). During these interviews, we sought information about developing and delivering effective lesson plans (See interview questions, Appendix C.1).

To get in touch with STEM teachers, we reached out to local principals of schools in the New Hampshire/Vermont area. We interviewed four STEM teachers, prior to which we asked for their informed consent (see preambles, Appendix E and Appendix C.1 for interview questions). Through these interviews, we wanted to find new perspectives on experiential learning and ways teachers implement traditional learning methods, such as lectures and handouts, alongside hands-on activities. Some of the local STEM teachers we interviewed were directly involved with the HBRF's tours at Hubbard Brook and could give valuable feedback.

Additionally, we reached out to educators at organizations in the local area such as the Watershed Education Specialist at NH Fish and Game, the Associate Director of Programs at White Mountains Science Inc., and an Education Coordinator at the Appalachian Mountain Club (see interviewees, Appendix D). We chose these interviewees due to their involvement in environmental education. Our goal was to learn about alternative methods of teaching students about the environment that could be implemented in the HBRF's lesson plans. We asked our interviewees questions regarding their program's most popular topics, their methods of gathering feedback, and the most important learning goals related to the environment.

We used content analysis of these organizations' websites for further research on teaching methods. Our process for content analysis of an organization's website was to supplement the interviews, finding more information and sources related to lesson plans and experiential learning methods. Content analysis is a method for processing and categorizing data into groupings (Given, 2008). Besides environmental education organizations' public websites, we also conducted content analysis on articles regarding education methods. If we found useful information in an article, we would look for sources cited on the website or online articles related to the topic in question. While analyzing, we especially focused on topics such as climate change, hydrology, ecosystem services, changing seasonality, phenology, and forestry because they were topics interviewees had emphasized.

In researching how to make lesson plans more helpful to teachers, we reviewed the Next Generation Science Standards (NGSS) for ideas of topics to include in the lesson plans, and to understand what is important to teach. The NGSS provides specific concepts that each grade level should know and we determined how best to incorporate these concepts into the activities that we designed. Additionally, we used the NGSS to adapt our activities for various grade levels. These sources were important to providing a genuine scientific experience in activities.

O3: Draft and Pilot Lesson Plans

We came up with a list of components for each lesson plan and the sources that helped us understand these components (See Table 1).

When we developed activities to meet learning outcomes, we considered potential constraints including location, timeframe, class size, and age. To address these considerations, we designed appropriate response procedures, planning out how to respond to events like weather changes, injuries, or broken materials.

Component of Lesson Plan	Sources
Teaching Topic	Interviewing Hubbard Brook staff, public school teachers, AMC educators, and systematic observation of tours
Learning Outcome	Interviewing Hubbard Brook staff, public school teachers, and AMC educators
Procedure	Interviewing Hubbard Brook staff and systematic observation of tours
Constraints / Adjustables	Interviewing Hubbard Brook staff
Required Resources	Interviewing Hubbard Brook staff
Student Assessment	Interviewing Hubbard Brook staff and public school teachers

Table 1: Lesson plan components and sources of understanding

We organized our data by topic and categorized interviewees as Hubbard Brook staff, school teachers, or members of organizations involved in environmental education. Using the data we collected in Objectives 1 and 2, we identified which topics to prioritize in lesson plans, learning outcomes, and approaches to increase student engagement. Our sponsor was the primary reference for deciding learning outcomes. Staying in regular touch with Hubbard Brook, we gave Mr. Leonardi the list of topics and desired learning outcomes and made adjustments based on his feedback. Once we had the desired topics and learning outcomes in place, we began drafting lesson plans.

These drafts served as preliminary stages of the lesson plans for the HBRF. We incorporated our findings on experiential and traditional learning methods, and brainstormed activities for each topic, based on their ability to engage students and their relevance to each activity. This brainstorming process was built upon the work from previous objectives. We analyzed interview responses from public school teachers and other educators for inspiration on the lesson plan topics. We maintained a dialogue with Mr. Leonardi about lesson plan constraints and protocol.

After drafting the lesson plans, we piloted them with fellow WPI students at our project center and our professors. In Figure 10, a student from WPI is measuring a stream's temperature, as per the lesson plan's activity. During the pilots, we took notes on clarity, enjoyment, and engagement to see what parts of the lessons needed reworking. After piloting the lessons with WPI students, we held a discussion and gave them surveys to gather feedback. Using this feedback, we made revisions to our first drafts of the lesson plans so we could then pilot with students. Revising the lesson plans was an iterative process with the aim to improve from week to week. At the end of each tour, we asked for quick feedback from the visiting students, teachers, and Mr. Leonardi. The tour guides provided teachers with feedback handouts at the end of tours and also asked for the students' reactions. We wanted to learn from the students what they enjoyed or found boring and what they most remembered. From the teachers, we wanted to learn what they saw as most helpful from the lesson plan, as a secondary education program. Lastly, we wanted to know from the Hubbard Brook employees who helped facilitate the lesson plan, what they found most useful or hindering so that they didn't feel bogged down by future iterations.

O4: Create Final Deliverables

The final objective was to convert the refined outlines into the finalized lesson plans. We compiled a document for each lesson plan describing the learning outcome, a detailed procedure, notable constraints, required resources, and safety reminders. They also provided notes of educational tips to help educators with the procedure depending on the teaching methods used, explanation of the individual responsibilities with time estimates, student learning outcomes, instructions for conducting activities, and protocols for unexpected events, like poor weather. The purpose of these documents was to gather all pertinent information into one place for each lesson plan and to ensure all involved parties were well-informed and able to act as a prepared and cohesive group.

We expected the focus of the lesson plans to be outdoors, active, and different from the usual experience in the classroom, so paperwork for students was minimized, only given when necessary. This promoted hands-on learning and avoided tedium that could turn away students. Paperwork mostly included data collection for activities and our short exit survey.

Figure 10: Piloting Water Quality lesson plan

Results and Findings

The data we collected helped us to create and refine four lesson plans for use at the Hubbard Brook Experimental Forest. Observing Mr. Leonardi's student tours was a vital source of information for designing our lesson plans. Some stops on the tours helped us define learning outcomes and narrow down which lesson plans were most important. For example, when Brendan stopped at an insect research station, we could see that many of the students were interested which inspired the insect observations and food web activity. Once we had selected the lesson plan topics, most of the learning outcomes were chosen through discussions with Mr. Leonardi or through interviews with school teachers. We thank Ms. Weatherbee, whom James Nicoll is interviewing in Figure 11, for her insight on writing the procedure and understanding the learning outcomes for the Phenology lesson plan. To design the lesson plans around the desired learning outcomes, we needed teaching methods that would engage students with each unique lesson. Through our interviews, focus groups, and tour observations, along with analysis of lesson plans from other organizations such as New Hampshire Fish & Game, we found teaching methods that helped us write procedures for the lessons and define our learning outcomes.

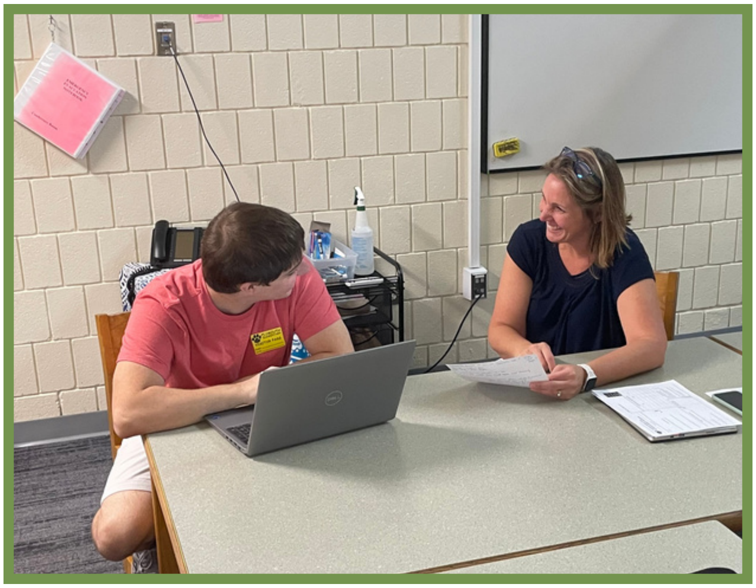


Figure 11: James Nicoll interviewing Jen Weatherbee

Teaching Methods

We found that the use of multiple methods is most effective in teaching students. We learned this through interviews with science teachers at Lisbon Regional School and with Stuart Hickey, an Education Coordinator in the AMC. Stuart Hickey stated that educators should rely on a "variety of tools to pull from" (Hickey, Stuart. Personal interview. 09/18/2023). It is helpful for students to read, watch, listen, and interact with a topic to reach understanding because different students learn best with differing methods. Through our background research, Lisbon teacher interviews, the NH Fish & Game educator interview, content analysis of articles, and our interview with Stuart Hickey from the AMC, we found that students are more engaged with hands-on activities when compared to traditional education methods. This approach can work for both high school and middle school students, so we didn't have to make different methods for teaching the same topic based on the age group of the students. The only change between the middle school and high school activities is the amount of detail and complexity in their measurements and discussions.

However, sometimes it is still difficult to get students to engage with a topic at all. We found that **the more a topic relates to the student's life, the more they will engage with that topic.** In an interview with Ms. Jellison at Lisbon Regional School, she stated that students are unlikely to enjoy an activity regarding invasive species because the impact on their lives is mostly indirect. We made an effort to focus on topics that we were sure students could relate to.

Incorporating roleplay or competition in a lesson will naturally get students interested. It may be difficult to get students to feel personally invested in some topics, so a trick educators use is to introduce a competitive or roleplaying aspect to the lesson. For example, Ms. Jellison detailed how she'd have the students pretend they were workers for an electrical company and that she was their customer. While wiring might not be the most personable lesson topic for students, the activity is made personal through the means of roleplay. In each of the lesson plans, we encouraged students to play the role of a scientist or ecologist studying the forest. We use a competitive element in the Tree Survey lesson plan to engage students.

Results and Findings

The students who can correctly identify a certain number of trees the fastest can win stickers or candy, motivating students to compete. This idea was suggested to us during the post-activity survey we held with WPI students, as seen in Figure 12.

Figure 12: Discussing feedback after a piloted lesson

While piloting the lesson plans, we received an important point of feedback regarding how to address student confusion. **Before beginning the activity, we found that giving a short verbal introduction to students gives them an understanding of what their goal is while providing a sense of intrigue.** For example, "Welcome students! You all are going to be my fellow scientists, conducting experiments and gathering data. Your data will be used in our organization's records for understanding the forest itself. Specifically today, we will be looking at the quality of the streamwater".

We also found that it is important to give a demonstration of the activity while all the students are still in one group. The tour guide should quickly conduct the activity and demonstrate how to take measurements so that students can see exactly what they are supposed to do, preemptively minimizing confusion students may have. Once we implemented the introduction and demonstration, we found that the middle school students we were working with had no problem figuring out what to do and they said that they "felt like scientists" which had them more engaged in the activity.

We found that it is important for the lesson plans to be adaptable for use at schools. We learned that it is unlikely that the lessons will be used exclusively at Hubbard Brook. Teachers may want to adapt them to their own classes and Mr. Leonardi may bring materials to schools to do the activities there. The lessons can be adapted by making changes to the materials they require. For example, some of the lessons rely on reference sheets to help students identify trees or leaf color and these reference sheets can be changed to match the environments or plant life around the school they will be used at.

Nature and Science Lessons at the HBRF

The topics we landed on are i) tree health and identification, ii) stream pH and water quality, iii) insects in the food web, and iv) fall and spring phenology. We identified these topics after numerous discussions and tours with our sponsor, Mr. Leonardi, the Young Voices of Science and Education Manager. The idea for measuring stream pH and water quality originated from interviewing Kayla Croteau, a Watershed Education Specialist at New Hampshire Fish and Game (Croteau, Kayla. Personal interview. 09/12/2023).

We designed the lesson plans to be used at both the Hubbard Brook Experimental Forest and in 6th-12th grade classrooms with the goal of sparking an interest in nature and science. As Mr. Leonardi shared, "even if each kid came away from the experience with only one thing that they learned or enjoyed, we would consider that a great success" (Brendan Leonardi, 2023). We sought teaching methods and science topics that would educate and engage students after their tour through the Hubbard Brook Experimental Forest. We found that a useful metric to gauge student interest in each topic was to count how many questions they asked at the related stop on the tour. Students who weren't interested in a topic would not ask questions about it. This was reinforced with data from student feedback and corroborated by Rose Dedham, a STEM teacher at St Johnsbury Academy, in an interview.

Results and Findings

Figure 13, the Tour Stop Questions Graph, shows the number of questions students asked at each stop along the watershed tour, which shows they are thinking about the topic more deeply, and care about learning more.

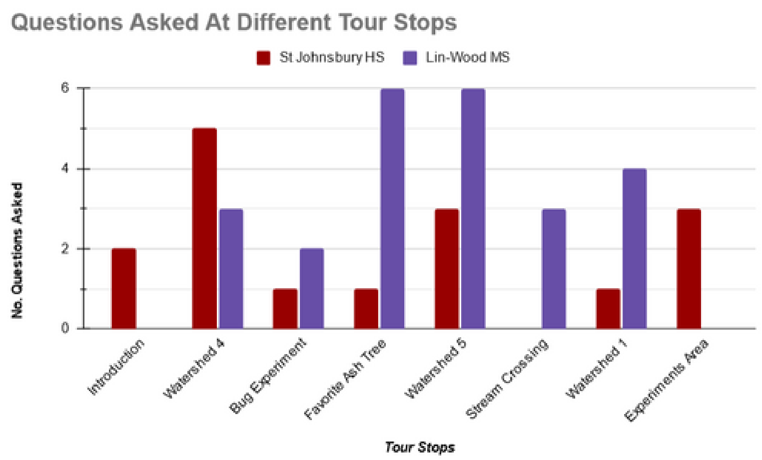


Figure 13: Tour stop questions bar graph

While piloting the Streamwater Quality lesson plan with three WPI students, we observed that some of the instructions were confusing. Also during the pilots, we noticed that participants lost interest in one part of the activity due to the number of steps involved. We did, however, learn that the animal observations portion of the activity got a lot of interest and that we could regain the focus of participants at that point before transitioning into discussion questions. After each of the lesson pilots, we received feedback from the participants and used this to make both small tweaks to discussion questions and add a much more detailed introduction and explanation before starting the activity. Additionally, we refined the lessons to incorporate shorter instructions and more hands-on engagement which we found improved retention of interest.

The pilots with our classmates and middle school students resulted in polished versions of the lesson plans. In the Tree Survey lesson plan, students identify the species of tagged trees with the aid of a tree ID sheet in a research plot. Afterward, they rate tree health based on a specific health scale. In the Streamwater Quality lesson plan, students measure pH, temperature, and total dissolved solids in a stream and record observations about the animals in and around the stream. Students are then led through a discussion about water quality and its effects on the forest and people. In the Food Web lesson plan, students observe sticky traps around Hubbard Brook and record abundance and diversity of insects, along with observing the surrounding area for signs of animals that live there. They discuss the possible prey and predator interactions of those animals and create a food web based on what they found. Finally, in the Phenology lesson plan, students make observations on seasonal changes such as the percentage of leaf color change in the fall, and leaf bud burst in the spring. They then compare their data to long-term data and consider what this tells them about the length of the seasons and changing seasonality in the region.

Some of the lessons we piloted made it clear that young students would not listen to directions all of the time and that certain considerations had to be made in case a group was hard to control. For example, we found that only low-grade sticky traps should be used in the Food Web lesson plan. We thoroughly warned students not to, but every time the Food Web lesson plan was piloted, students touched the sticky traps. Teachers should expect students to touch the sticky traps, so the research-grade ones as shown in Figure 14, should not be used.

Figure 14: Research-grade sticky trap (Brendan Leonardi, 2023)

Results and Findings

Learning Outcomes

When designing the lesson plans we decided to focus each plan around a few concrete learning outcomes. This was so that we could provide teachers with clearly defined goals for running the lesson. The learning outcomes are categorized as either new information, hard skills, or soft skills. Hard skills are measurable abilities such as data collection, whereas soft skills are intangible, an example being critical thinking. These outcomes came from our interviews with local teachers and observations during student tours.

We found that many students don't understand the close connection between water sources and plant life. Kayla Croteau explained to us that students easily understand the fact that a water's quality would have a direct effect on the forest, yet they struggle when it comes to understanding why aspects such as pH, total dissolved solids, and temperature affect the forest (Croteau, Kayla. Personal interview. 09/12/2023). Consequently, we developed a stream pH and water quality lesson to help address this. Additionally, in the Streamwater Quality lesson, we emphasize that poor water quality in a forest does not just harm the local ecosystem. The same water ends up in their glasses at home. This gives them a connection to the forest and the water that comes from it. Additionally, one of the HBRF's main goals is to track watershed chemistry and stream flow as it helps them understand the health of the forest (Leonardi, Brendan Personal interview. 09/30/2023). To address this in our Streamwater Quality lesson, students are asked to measure the pH, temperature, and total dissolved solids in a stream (See Appendix I for full lesson plan details). Through this exercise and the use of discussion questions after the activity, they could directly connect the importance of water quality with the ecosystem's health.

Teachers appreciate assistance in providing lesson plans related to climate change. According to Ms. Jellison, a high school teacher at Lisbon Regional School, many students don't believe in climate change or global warming. Hannah Vollmer and Amey Bailey, US Forest Service employees, stated that teachers often request assistance in teaching climate change (Personal Focus Group, 09/21/2023). It is a topic some teachers wish was more thoroughly taught, but find difficulty in teaching it due to its basis on long-term data and because it is not easily observed in one week of activities (Dedam, Rose. Personal interview. 09/22/2023). We attempted to fill these gaps with the Phenology lesson plan. For example, to get students thinking about climate change, the Phenology lesson plan can inform them about data that would be too subtle or obscure otherwise, due to taking the measurements both in the fall and spring. When Hubbard Brook provides past data to compare to, they might record measurements that show that winter is getting shorter, and they will be encouraged to think about and discuss the causes of their observations.

One piece of feedback we received from multiple teachers was that state exams in New Hampshire place a high priority on interpreting data and graphs. Due to this, we designed our Tree Survey lesson plan around having students collect data that can be displayed in graphs and compared to previous data. It is easier for students to understand trends in data if they collected the data they are using, so our lesson is designed around teaching students data collection methods and how to enter information into a datasheet. Students record information about tree species, diameter, and health so they are learning about tree identification while also practicing skills they will need for exams (See Table 2, below). Additionally, they learn to tag their trees and develop data organization methods. Ensuring that students follow these data collection methods not only helps the students but allows the HBRF to use the data that the students collect in their research. Mr. Leonardi stated that he would also double-check the data to ensure its accuracy for later use.

Tag Number	Diameter (In)	Species	Tree Health (1-4)	Beech Bark Disease (0-4)	Notes/Observations

Table 2: Tree Survey Datasheet

Results and Findings

An important soft skill for students to learn is critical thinking. Most of the Next Gen Science Standards related to our lesson plans have mentioned critical thinking and understanding connections in nature. The Food Web lesson plan was designed to get students thinking about the animals that live in the forest, how they coexist, and how they affect us. Many students do not appreciate the importance of insects, but it is important for them to understand their part in the ecosystem. During the group activity, students made their own food web with string and were asked to cut the string wherever there was an insect. Through this activity and the following discussion questions we had students thinking critically about the vital role each creature plays in the ecosystem and they got to see how their food web fell apart when insects were removed. A full explanation of our lesson plans' desired learning outcomes and the connected activities can be seen in Table 3 (See Appendix I for all lesson plan materials).

Many students hate bugs, especially when being surrounded by them on the tour, but it is important for them to understand their part in the ecosystem. The food web activity had students observing insects on sticky traps and recording how many there are along with observing the surrounding area for signs of animals that live there. During the following group activity, students made their own food web with string and were asked to cut the string wherever there was an insect. Through this activity and the following discussion questions we had students critically thinking about what role bugs play in the ecosystem and they got to see how their food web fell apart when insects were removed. Overall this activity pushed students to think critically about the food web and the vital role each creature has in it.

A full explanation of our lesson plans' desired learning outcomes, and the connected activities can be seen in Figure 18. (See Appendix H for all lesson plan materials)

Lesson Plan	Learning Outcomes	Activity
Tree Survey	-Learn data collection methods used by scientists and researchers in the field -Learn to identify and evaluate trees accurately	Students will tag and identify tree species within a research area. The identification will involve an ID sheet that they can use for clues to figure out a tree's species. Additionally, they will be working to rate trees based on their health.
Stream Water Quality	-Understand the connection between the forest, water quality, and the people and animals that use the water -Improve critical thinking skills by providing open-ended questions about the effects of water quality	Students will measure pH, temperature, and total dissolved solids in a stream and record observations about the animals in and around the stream. Next, they will be led through discussion about water quality and its effects on the forest and people.
Insects and the Food Web	-Understand the importance of insects and how all members of an ecosystem are important to maintain balance in the food web -Improve critical thinking skills by considering connections between animals	Students will observe the sticky traps around Hubbard Brook and record different species of insects found on each one. At each sticky trap, students will observe the surrounding area for any signs of animals. They will discuss the possible prey and predators of those animals and create a food web based on what they found.
Fall and Spring Phenology	-Learn about how the forest reacts to the changing of seasons -Relate season length to climate change -Compare data to long-term records	Students will make observations on seasonal changes such as percentage of leaf color and leaf bud burst. They will then compare to long-term data and consider what the data tells them about the length of the seasons.

Table 3: Lesson plan outcomes and descriptions

Recommendations

Lesson Plan Alterations and Ideas

We propose six recommendations about lesson plan alterations to improve student engagement and to adapt lessons for use in a school or at other organizations.

We recommend that teachers change the organism cards used in the Food Web lesson plan to reflect their own local environment. This will help make the activity more personal for the students and better connected to the surrounding environment where the content is being taught. For example, at NH Fish & Game, they could use cards for guppies, catfish, mayflies, ducks, and algae. Similarly, the tree identification sheet included in the Tree Survey lesson plan would need to be adapted to whichever set of trees are in the area where the activity is being run. We prepared eleven preselected organism cards, for piloting the food web activity with Lin-Wood students shown in Figure 15. We selected organisms that would make insects a major part of the food web, as it better related to the lesson.

Figure 15: Lin-Wood students creating a food web

The Phenology lesson plan requires students to record data about the percentage of leaf color change. This could be hard to understand without visuals to support them so we recommend that a reference sheet be made showing pictures of trees at multiple stages of color change. This reference sheet would allow younger students to understand what different leaf color percentages look like. Creating this reference sheet was outside the scope of our project. Pictures would need to be taken of the same trees as they began changing color a few weeks before we began work on the Phenology lesson plan and would not finish changing color until after our project term concluded. For the Spring Phenology lesson, **we recommend adding an interactive game that demonstrates the effects of changing seasonality.** One such example would be a moose and tick game which conveys how changing seasons increase tick populations and consequently decrease moose populations. Additionally, **we recommend adding a graph of the timing of spring leaf out so students can compare their observations to Hubbard Brook's long-term data.**

We recommend Hubbard Brook educators make four instructional videos to introduce students to the Hubbard Brook Research Foundation and describe the activities and concepts students will engage with on their tour. We wrote scripts for videos for each of the four lesson plans. Each of the four videos would begin with a general introduction and then transition into the lesson-specific information.

We recommend that the Hubbard Brook Research Foundation continues to develop more lesson plans. We generated a broad list of potential topics that we narrowed down to four. The other brainstormed topics can serve as the basis for more environmentally-themed lessons. Additionally, the finalized lesson plans can act as templates for future lesson plans and activities to be produced and run at the HBEF.

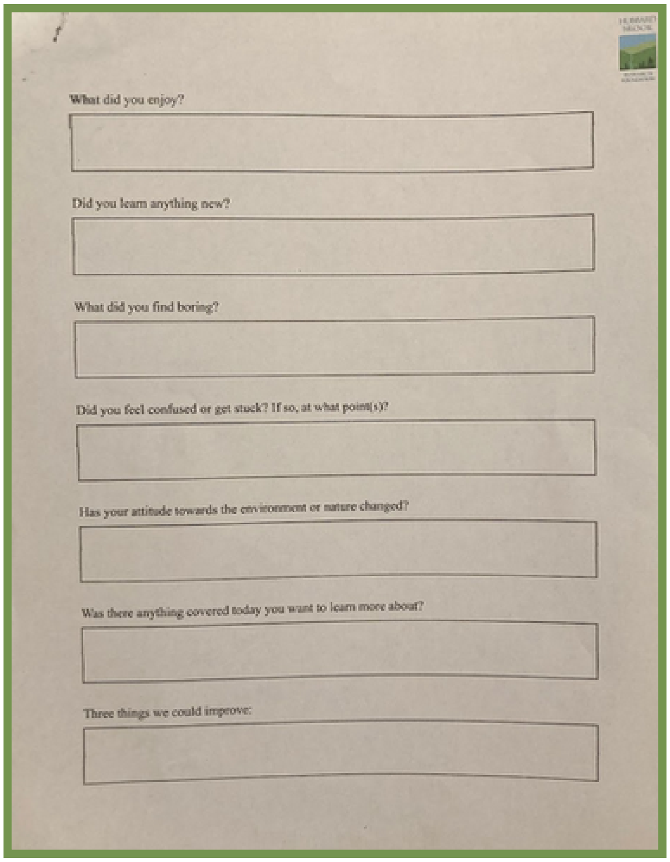
Student and Teacher Feedback

We propose two recommendations about the continuation of lesson plan feedback.

We recommend Hubbard Brook staff continue to utilize post-tour student/teacher surveys to obtain feedback and make any revisions that seem necessary. No product is fully perfected even after half a dozen test runs; improvement is an ever-lasting process.

Recommendations

We recommend against using student feedback forms with open-ended questions. With the feedback form we used (See Figure 16 below), we gained valuable information from student feedback but also received some irrelevant comments that we needed to filter out. More specific questions would reduce the time spent on this process.


What did you enjoy?

Did you learn anything new?

What did you find boring?

Did you feel confused or get stuck? If so, at what point(s)?

Has your attitude towards the environment or nature changed?

Was there anything covered today you want to learn more about?

Three things we could improve:

Figure 16: Post-lesson feedback form

Travel Logistics

We propose two recommendations about methods to make lesson plans more accessible to schools by either making lessons portable or helping classes travel to Hubbard Brook.

We recommend the HBRF modify the activities for usage on school grounds or support schools in having more field trips by subsidizing the cost of a bus. The high transportation costs for field trips may force schools to forgo participating in HBEF tours. Thus, by adapting the activities to be used at the schools, students could learn almost identical information and still grow a love for nature. The HBRF does not currently have enough funding to subsidize bus costs regularly, though some changes in their budgeting could be made to address that. The HBRF already has a project called “Hubbard Brook In A Box” (See Figure 17) which could be an effective resource for inspiration on making lesson plans portable.

We recommend that future lesson plans incorporate long-term data collection. This can contribute to a database that allows students to compare their measurements with previous students. The Tree Survey lesson plan incorporates this data collection method so Hubbard Brook researchers can benefit from student data. Teachers can use the long-term data in classes to improve students’ abilities to organize and analyze data. This eliminates the travel costs needed to return to Hubbard Brook on a regular basis to interact with the data.

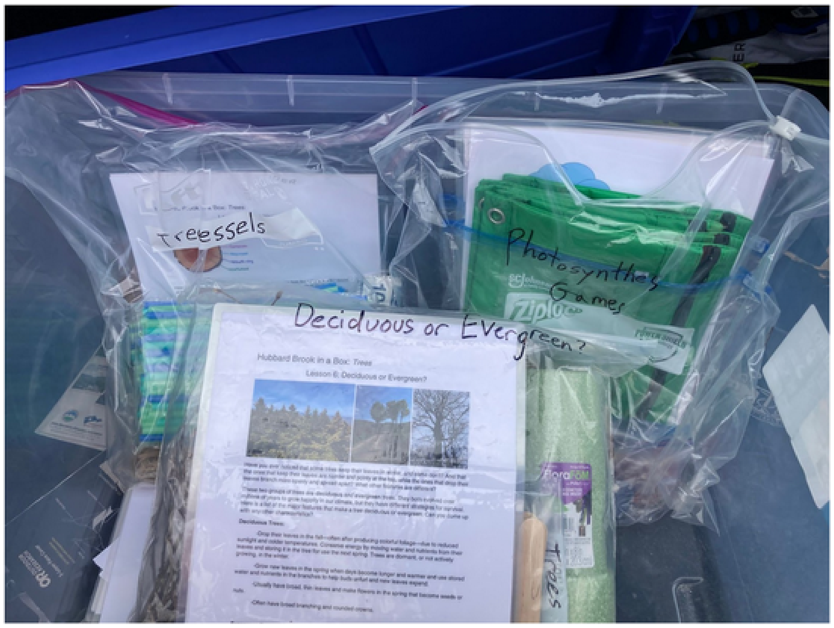


Figure 17: Hubbard Brook in a box

Conclusion

Our project, sponsored by the Hubbard Brook Research Foundation, was to develop lesson plans to educate students on the environment in the White Mountains. The lesson plans are designed to benefit students, Hubbard Brook researchers, and teachers. Students will be able to learn more about the environment through experiential learning. Hubbard Brook researchers who handle education, as Mr. Leonardi, will have fully planned out and polished lesson plans that can easily be used to teach students about various topics. We hope these lesson plans will inspire students to explore further environmental education and to keep the environment in mind if they enter a STEM field. We believe students exposed to these lessons will benefit from having a new perspective on the forest and new knowledge that they can apply in their future schooling and career fields. In addition, researchers at the HBRF can benefit from the data students collect in the tree survey. Teachers will benefit from having new activities either at Hubbard Brook or at their school that they can relate to their classes.

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