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Hemp-lime as a tool for undergraduate research and teaching experiences

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The continued growth of hemp-based products in construction is a subject that many students in the Sustainable Biomaterials department at Virginia Tech are interested in pursuing as a career. In response to this interest, the authors have conducted several special study courses and independent research activities with students to increase their understanding of hemp and other bio-based materials in construction. Experiential learning activities such as these are now in high demand, are being encouraged at Virginia Tech and are recognized as important by employers. The purpose of this article is to describe an evolution of educational activities and suggest best practices for other educators to help students gain experience with hemp-based products while preparing them for careers in construction. When discussing novel construction materials such as hemp-based products, there is often little information available as to the use and application of these in teaching and project learning. By using a combination of classroom lectures, laboratory activities, and active engagement with industry professionals, teaching professionals can be effective learning venues to prepare students for career paths.

KEYWORDS

hemp-lime, experiential learning, undergraduate research, undergraduate teaching, industrial hemp

1 Background

Climate change is currently the most pressing issue facing humanity [Stern, 2006; Intergovernmental Panel on Climate Change (IPCC), 2014]. The effect of biogenic carbon released into the atmosphere has had a profound and shocking effect upon the environment, increasing global temperatures, increasing sea levels, and creating more erratic and chaotic weather patterns. Climate models developed by the Intergovernmental Panel on Climate Change (IPCC) demonstrate predicted rise and worsening of global temperature because of human-related greenhouse gas emissions [Shi et al., 2015; Intergovernmental Panel on Climate Change (IPCC), 2014].

In particular, the worldwide construction industry is the largest consumer of material with the largest single energy use in the world (Krausmann et al., 2009). Annually, buildings generate 40% of global greenhouse gas emissions through operational and embodied energy (Architecture 2030, 2023). In the US, buildings consume approximately 70% of domestically produced energy. Aside from the direct 40% of GHG emissions attributed to construction, many of the manufactured sources are dedicated to producing goods and services related to the function and use of buildings (furniture, cooking equipment, entertainment) (Architecture 2030, 2023).

Mitigation efforts to address climate change have focused on strategies to reduce the production of carbon dioxide and GHG emissions, a process known as de-carbonizing (Barry and Johnson, 2022). The act of lessening production of GHG sources has been explored by several authors (King, 2017; Hausfather and Friedlingstein, 2022). Buildings can play a large role in decarbonizing our environment. Barry and Johnson (2022) presented a strategy for decarbonization of the building sector, focusing on changes in policy, accounting of carbon use in buildings, market transformation, increased investment in energy standards, addressing issues of current building stock, workforce development, and social equity. The main strategy for decarbonization efforts involves addressing both the operational carbon and embodied carbon associated with buildings. Operational carbon refers to GHG emissions related to energy production for the space conditioning, heating, lighting and power used. Embodied carbon refers to the GHG emissions produced as a function of the manufacture, use, installation and transportation of building products and construction processes (Dixit, 2017).

Several authors have advocated the use of wood and plant-based fiber sources [Churkina et al., 2020; Intergovernmental Panel on Climate Change (IPCC), 2014; McKinsey and Company, 2009] as methods of carbon capture through sequestration and incorporation in buildings. Currently, the only economical and efficient method for the capture of carbon from the atmosphere is the growth of plant-based fibers, which can be harvested and then regrown to produce more fiber. Innovations such as mass timber and the continued use of annual crop fiber can accelerate rates of carbon capture (King, 2017).

1.1 Alternative building materials

Alternative building materials (ABM) are defined as low-cost materials that "aim to reduce or eliminate the environmental impact of the construction" (Orhon and Altin, 2019, p. 728). ABMs can include materials that are energy efficient, resource efficient, reduce embodied energy, minimize greenhouse emissions, use rapidly renewable materials or have recycled content. The use of alternative building materials is mainly centered around plant-based fiber not obtained from trees and has the potential to become important in the future. While wood fiber is a renewable and sustainable material when harvesting and land conservation practices are performed correctly, the volume and need of fiber sources has the potential to tax our forest resources, leading to an increased focus on quicker rotation crops.

The Department of Sustainable Biomaterials at Virginia Tech focuses on preparing students for careers focused on the manufacturing, production, and use of forest products or other plant-based biomaterials. As a national leader in materials education, the department uses a variety of experiential learning (EL) methods for instruction. EL is a current trend in higher education pedagogy to promote active learning using real-world experiences (Kong, 2021). EL is largely based on Socratic practices and acts to pair knowledge with real-world situations including professional experience. Both authors have used EL methods in the development of project-based learning classes, where academic concepts are tied to real-world implementation scenarios. In 2017, the Department of Sustainable Biomaterials was awarded an exemplary department at Virginia Tech based upon the strength of EL pedagogy (Virginia Tech, 2018). Recent student interest has focused on various ABMs including hemp, bamboo, mycelium, and other natural materials. Current students show a high level of environmental literacy and are interested in entrepreneurial careers using non-conventional materials.

Kolb and Kolb (2005) noted that research efforts on EL have become interdisciplinary, which characterizes the student knowledge related to the Department of Sustainable Biomaterials, where students gain an appreciation of technical details, business knowledge and the use of sustainability assessment tools. EL theory characterizes for different learning approaches – diverging, assimilating, converging and accommodating – and further defines these areas as combinations of the four learning styles (experiencing, reflecting, conceptualizing, acting) (Kolb and Kolb, 2005). The EL experiences incorporated in the Department of Sustainable Biomaterials curriculum emphasize the use of reflection and conceptualization concepts to lead to action and experience, then complete the cyclic nature of this learning path by allowing more reflection, and re-conceptualization.

1.2 Industrial hemp as a fiber source

Hemp (*Cannibis sativa*) is one of the earliest cultivated crops, first used by humans approximately 8,500 years ago. Hemp has been used originally as a fiber source for cordage and canvas. Oils from hemp have also been used and are dominated by a current emphasis on cannabidiol (CBD). The story of hemp use is not complete without a mention of marijuana, an offshoot of hemp which contains high concentrations of tetrahydrocannabinol (THC), a psychoactive compound, that is currently regulated as a Schedule 1 drug (Malone and Gomez, 2019). Distinctions between hemp and marijuana are sometimes difficult and both plants have been banned from use. In recent years beginning with the Agriculture Improvement Act of 2018 (2018 Farm Bill), production of hemp in the United States was allowed. Current production has increased to where some states now allow growth of hemp with consistent monitoring to maintain THC levels less than 0.3 percent dry weight (Congressional Research Service, 2019).

Currently, most hemp production in the United States is being grown for oil production. However, there are optimal varieties available for fiber production, which is more common outside of the United States. Hemp fiber can be subdivided into two categories – bast, or outer fiber, and shiv (hurd) or inner fiber. The bast fibers are long, thin, continuous fibers with high tensile strength. Bast fibers are used in the production of clothing, insulation, and cordage. Hurd fibers are short, brittle and punky in nature, and are used in hempcrete production, as well as growth media, pulp and animal bedding (Fike, 2016).

1.3 Hemp-lime (hempcrete) products

Hemp-lime, formerly known as hempcrete, is a mixture of hemp hurd, lime plaster and water (Gołębiewski, 2018). The material is tamped into place and used as non-structural insulation material. The name was changed to hemp-lime since hempcrete sounds like concrete and may give the false impression that hemp-lime is a structural product. Insulation values of hemp-lime is R-2.08 per inch (Gibson, 2016), which is lower than conventional fiber-glass batts. Various manufacturers including Hempitecture, Inc.; Americhanvre; and American Lime Technology, among others, are available in the United States. Compared to other insulation types, hemp-lime has one of the lowest embodied carbon amounting to 0.142 kg CO_2eq./kg, compared to 1.35 kg CO_2eq./kg for fiberglass batt insulation (King, 2017). Therefore, even with a lower equivalent R-value of thermal resistance, hemp-lime can provide equivalent insulation with a reduced embodied carbon emission. An advantage of hemp-lime over conventional batt insulation materials is that hemp-lime can be extended beyond the stud wall cavity and be placed over top of the studs to prevent thermal bridging. Finishing materials for hemp-lime use a lathe and plaster system capable of withstanding local environmental conditions.

The disadvantages of hemp-lime are related to the installation of the material. Hemp-lime must be troweled into the wall section and restricted by forms to depths of 18 to 24 inches at a time before curing is complete, and the forms can be removed. This represents a significant amount of labor and time on the jobsite. Another disadvantage is the difference between working with bio-based fibers versus mineral aggregate. The hemp hurd itself will absorb a portion of the water used for the mix, so careful understanding of the mix is needed. Several companies (American Lime Technology, and others) sell pre-measured mixes which helps overcome this challenge, specifically on small scale projects.

1.4 Purpose

The purpose of this article is to discuss previous teaching activities and suggest best practices for other educators to conduct such classes to help students gain the best experience in using hemp products, and other ABMs. When discussing novel construction materials such as hemp, there is often little information available as to the use and application of these projects. The use of EL methods can be helpful to engage students and allow for more creative exploration. EL was accomplished using a combination of classroom lectures, laboratory activities, and active engagement with industry professionals. The following sections include a description of the class, followed by perceptions of the students and faculty involved.

2 Classroom activities

Over the past 10 years, the Department of Sustainable Biomaterials has offered various special study and independent research experiences for students to increase their understanding of hemp and other bio-based materials in construction. Teaching using project centered learning seemed a natural fit with hemp-based course content. This section is divided into two different areas, detailing past classroom and research activities, where hemp was either featured or a major topic of discussion. Then, the most recent class, SBIO 3984 Mycelium and Hemp, presented in Fall 2023 is discussed in depth.

2.1 Previous classroom and research activities

2.1.1 SBIO 3454—society, biomaterials, and bioenergy

SBIO 3454 is taught annually within the Sustainable Biomaterials curriculum. The purpose of the class is to explore the relationships between the uses of biomaterials and bioenergy on society in general. The class consists of lectures related to various topics and then allows time for a final project which expresses student knowledge.

Beginning in 2015, before the re-introduction of hemp as an agricultural commodity to Virginia, students in SBIO 3454 decided to work on projects focused on hemp. Hammett facilitated the visit of a colleague from the Virginia Industrial Hemp Coalition (VIHC), who met with students and introduced the class to two industrial hemp entrepreneurs. Through contacts with the VIHC, a supply of industrial hemp was sent for use. Due to an administrator's concerns over the industrial hemp, the authors were asked to keep the fiber in a locked closet. It should be noted that there are no concerns about the legality of owning industrial hemp fiber.

In 2016, the SBIO 3454 class received a visit from the Hemp Road Trip, a group of hemp entrepreneurs and advocates who were traveling across the country to Washington, DC to encourage adoption of hemp related legislation. The Road Trip included displays and samples of hemp-related products. The inclusion of the Hemp Road Trip was helpful to give students access to tangible products and discuss hemp materials with experts.

2.1.2 SBIO 4984—researching opportunities for industrial hemp

In the spring of 2017, a new course was organized and offered for three years that was based on a model that fostered research skills and confidence. Students met with faculty weekly and then reported on the results of their semester-long hemp projects at a public forum. Interest by the public had grown so that over 40 local entrepreneurs and farmers attended the event. For several years before COVID, these student presentations were an annual event attracting collaborators, other students, and local stakeholders. The experience was valuable as the students presented their results and responded to questions from the general audience, many of whom were anxious to start their own hemp enterprise.

From this class, one student presented their research at an international conference in Japan (Madrazo et al., 2018), while another student chose to attend graduate school to study hemp products. Examples of research projects included measuring the fire-retardant qualities of hemp-lime, development of novel packaging cushioning materials, using alternative bonding agents for hemp-lime, and opportunities to improve the composition and use of hemp-lime products. The course was offered again, titled "Advanced Research in Industrial Hemp" in 2018 and included visits to local processing facilities, local entrepreneurs, and to the Virginia Tech industrial hemp research plots.

2.1.3 SBIO 3334—non-timber forest products

Interest in hemp grew further and was incorporated in a third regularly offered course which focused on non-timber forest products and specialty crops. This course used hemp as a class-wide focus crop and offered projects in hemp-related subjects besides hemp-lime. Course learning objectives included: evaluating hemp as a sustainable biomaterial using sound research and critical thinking; describing significant changes facing the production and use of hemp; interpreting the key issues related to the cultivation, manufacture, utilization, and marketing of hemp products; and identifying reliable sources of information (research) to support sound decisions about hemp production and use.

2.2 SBIO 3984: mycelium and hemp

From the previous teaching listed above, the most impactful teaching methods appeared to be a combination of lecture-type instruction and project-based research. As the next iteration of EL related to hemp, Hindman and Hammett offered an independent study class called "SBIO 3984: Mycelium and Hemp" in the fall semester of 2023. As stated, "The purpose of the course was to explore the emerging uses of mycelium and hemp in construction. The class will consist of experiential learning to understand the sources, manufacturing, use and deconstruction of mycelium and hemp products in construction." Students were evaluated based upon weekly homework assignments, and a final project, consisting of biweekly progress reports, and a final presentation.

2.2.1 Class activities

The class activities are shown in Table 1. First, a general introduction to the course was given. Students were oriented to the goals of the class. Next, students were introduced to research methods by visiting the college librarian and reviewed previous student projects. These topics prepared the students for EL practices and the rest of the course. The research methodology and steps were developed in the courses we discussed earlier.

The third activity was an in-depth literature review. The focus was on discerning and finding credible sources. Important parts of the literature review included detailing the manufacturing process, including material, energy and time needs, the use of these products in buildings including the testing and measurement to compare to other materials, and the life cycle analysis measurement techniques and results for each material. The literature review was an interactive process, where students are tasked with determining the direction of literature, while the faculty members filled in gaps.

The fourth activity was for the students to begin developing final project ideas. These were independent, research-based investigations of one of the key materials – mycelium or hemp. Based upon student's analysis of the literature review, projects were initially chosen. These projects were further refined by the experience and interaction of guest speakers and laboratory experiences.

Guest speakers and laboratory experiences were used to complete the state-of-the-art understanding of the current use of mycelium and hemp products. Laboratory experiences used labs in both the Department of Sustainable Biomaterials and the Department of Industrial Design at Virginia Tech, while guest speakers included local field trips to hemp producers, CBD manufacturing facilities. For other guest speakers, Zoom sessions where students could interact with the speakers in real time were employed. This allowed a group of speakers from across the United States focused on architectural design, manufacturing of industrial hemp fiber and national trade associations to be brought into the classroom. Prior to guest speaker engagement, students were given copies of the speaker's bio or relevant research to be prepared with questions and discussion.

TABLE 1 SBIO 3984 class activities.

1. Introduction to course
2. Introduction to research methods
3. Literature review on mycelium and hemp products
a. Manufacturing process
b. Use in buildings
c. Life cycle/environmental footprint
4. Develop ideas for final projects
5. Guest speakers/field trips to visit experts
6. Visit to labs to demonstrate how products are made
7. Conduct data collection for final projects
8. Present final projects

2.2.2 Individual student projects

The final portion of the class consisted of an independent project addressing a physical research question. Based on previous teaching of EL practices, the development of a research timeline was found to be the most helpful system (Table 2). The purpose of this timeline is to help students maintain focus on achieving milestones and progress throughout the semester. The activities were also designed to help students develop research confidence and communication skills by encouraging frequent output. Two of the final projects for the Mycelium and Hemp class are profiled as examples.

> *Project #1: Creating Structural Hemp Hurd Blocks Using Natural Reinforcement Materials.*

The purpose of this student project was to explore the use of hemp-lime materials paired with reinforcement to become structural elements of a building. Several companies have succeeded in producing structural hemp-lime material, including Just BioFiber and HempBLOCK USA. The student attempted to create structural elements by pairing small wooden elements to create interlocking "LEGO" style bricks of hemp-lime.

Figure 1A is a photograph of moldable sections showing the wooden interlocking parts. Challenges with methods to mold and unmold the bricks were observed, and the success of the blocks was limited by the brittle behavior of the hemp-lime material. The wooden structural elements used were chosen to provide the structural form, while the hemp-lime material was meant to serve as cover and insulation.

> *Project #2: How Does the Inclusion of Portland Cement Affect the Mechanical and Thermal Properties of Modified Hemp-Lime?*

The purpose of this student project was to explore the use of additives such as Portland cement and how these additives affected the mechanical strength and thermal properties of hemp-lime. As the hemp-lime product is not structural and most common wood structural tests would not apply well, the student developed a separate test protocol called the "blizzard test," named after the popular Dairy Queen dessert where servers hand you the ice cream inverted to demonstrate the cohesiveness of the product. The student would unmold the hemp-lime (Figure 1B) and take an initial weight of the block. The student would then subject the block to certain moves – rotations, inversions, etc. – and remeasure the weight of the block after each combination of motions.

TABLE 2 Research timeline for hemp-related research projects (16 week semester).

Week	Goal and activities	Outputs/assignments	Comments
1	Establish research topic, justification, objectives and outputs	Complete proposal and submit for approval	Review of syllabus, discuss research topics
2	Initial plan for research	Initial outline; obtain research resources	Instructor approves proposal; view hemp products in SBIO lab
3	Plan basic research; determine methods to be used	Begin literature review; meet with librarian	Credible sources; Progress report #1
4	Library and online searches; plan interviews with specialists, field trip to sites in/near Blacksburg	Continue literature review; annotated bibliography	Field trip to meet hemp entrepreneur; mentoring meetings
5	Basic research to locate additional sources: refining topic and methods	Expand outline; attend research seminar #1; begin interviews	Progress report #2
6	Locate resource persons, determine testing sites or surveys	Reflection on research seminar; set up testing	Plan field trips; meetings w/specialists
7	Present full outline, with timeline for project completion	Interviews with resource persons	Meet with instructor, progress report #3
8	Conduct site visits, interviews, meetings with resource persons	Interview reports, expand lit. Review	i.e., hemp companies or production sites
9	Testing and data collection	Attend research seminar #2	Documenting results
9	Testing and data collection	Report on seminar #2	Progress report #4
10	Finish testing, analyze results	Begin results write up	Upload early draft
11	Compile results, writing	Conduct reviews of peer's draft report	Review peer's outline and early draft report
12	Analyze results, writing, further literature review	Finalize results and revise rough draft	Meet with instructor; progress report #5
13	Writing final report	Invite attendees to final presentation	Post 2nd draft report for review
14	Prepare draft presentation of results (slides, handouts)	Revise and post draft presentation	Individual meeting with instructor
15	Present results and recommendations in seminar for peers and resource persons	Evaluate peer's research presentations	Submit feedback on to peers after seminar
16	Incorporate/respond to comments from evaluators and audience incorporated; revise and finalize reports/outputs	Submit final report, annotated bibliography	With instructors discuss questions and potential outlets for research

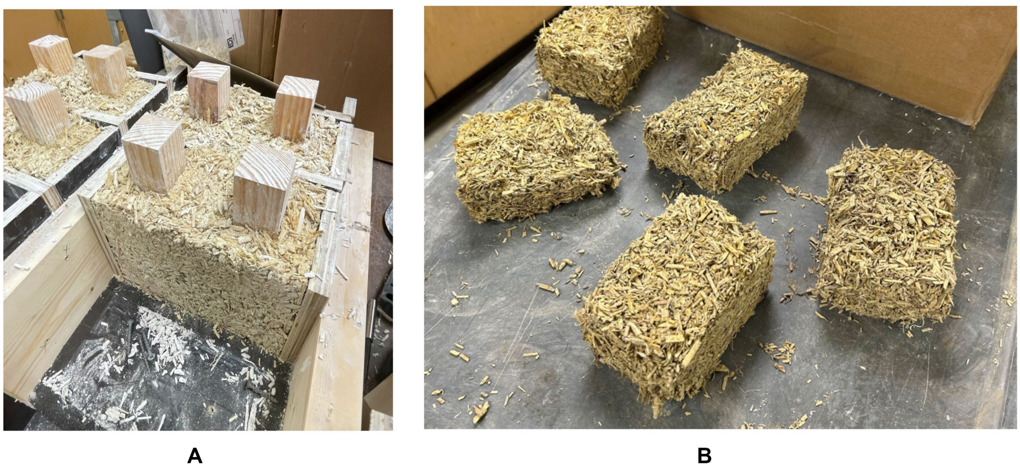

FIGURE 1
(A) Molded hemp-lime blocks from Project #1, **(B)** hemp-lime bricks with various additives from Project #2.

2.2.3 Student perceptions of SBIO 3984

The results of the student perceptions of learning (SPOT) survey conducted after Virginia Tech are shown in Table 3 based on feedback from two of the four students in the class. This data was presented anonymously to the instructors after all grading was concluded, so no student demographics are possible to ascertain. Before using this data, the authors conducted a preliminary query with the Internal Review Board (IRB) of

TABLE 3 Results of student perceptions of teaching (SPOT) survey.

SPOT question	Student rating (out of 5.0)
The instructor was well prepared.	4.5
The instructor presented the subject matter clearly	5.0
The instructor provided feedback intended to improve my course performance	5.0
The instructor fostered an atmosphere of mutual respect	5.0
Overall, the instructor's teaching was effective	4.5
I have a deeper understanding of the subject matter as a result of this course	5.0
My interest in the subject matter was stimulated by this course	5.0

Virginia Tech. Because of the previous anonymization of the data, no human subjects' permissions were needed.

The scores to the responses shown in Table 3 were scaled to 5.0 and represent responses from two of the four students in the class. All ratings were 5.0, except questions about teacher preparedness and teaching effectiveness. Additionally, the students were asked open-ended questions shown below.

In response to the question "What did the instructor do that most helped in your learning?"

- *Dr. Hindman was great about providing resources to students and helping out with getting materials and connecting us to people who could help.*
- *Similarly, Dr. Hindman has always been available and there to direct and guide me when I've had specific questions about the content of SBIO and hemp/mycelium. I think without the mutual support from both, this class would not have worked out.*

In response to the question "What could you have done to be a better learner?"

- *bring more ideas to classes that I have/have heard throughout the months.*

In response to the question "Please add any additional comments regarding the course and/or instructor here."

- *I think that everyone struggled with time management. The amount of time that was spent on the material overview of hemp and mycelium made it difficult to implement the projects that we planned. Perhaps assigning background readings on hemp and mycelium before the class begins would help since the overview took a long time. Designing, amending, and completing a project takes a long time, and we need as much time as possible to get things done.*

Comments from students noted that the inclusion of multiple topics may have seemed too much. Overall, the authors believe the students benefited from the course and learned more in-depth materials about both mycelium and hemp. In general, responses were positive, with some desire for more knowledge and in-depth work.

3 Overall faculty perceptions of hemp classes

Based upon the experience of leading classes and research experiences focused on hemp-lime, the authors listed the following perceptions which should be addressed for other faculty interested in teaching topics related to hemp in construction. Overall, the inclusion of hemp-lime in the curriculum was considered a success and hopefully future efforts can incorporate this material into the main body of the Sustainable Biomaterials curriculum.

3.1 Challenge of legalization

One of the most persistent issues surrounding the use of hemp-lime is the perception that industrial hemp is cannabis. This issue was made clear to us early in our teaching when administration expressed concern about faculty possessing industrial hemp. Even among academics, there are many misperceptions and stereotypes related to the product. The issue is made murky by the fact that industrial hemp, which is defined as containing less than 0.3% THC, can produce elevated levels of THC during the growing process in response to environmental stressors such as extreme drought. This high THC level has led to destruction of crops and perceptions of higher risk associated with industrial hemp growing among farmers.

The authors felt strongly that the best approach to address concerns about industrial hemp vs. cannabis was to be honest and factual with our students. We openly discussed the differences between the two crops and highlighted the uses of industrial hemp and benefits to society. This view was shared by many of the guest speakers we invited, who mentioned that the legalization of industrial hemp growth has a tie to the cannabis industry. Making sure our students are prepared to describe their position and understand the issues of product legalization is important as they enter the workforce where they may face more opposition to industrial hemp use.

3.2 General interest remains high

The topics and information shared in the class were very relevant to students and students approached the class very professionally, spending time and contributing deep work. Over a year after teaching this class, students still mention the course and its impact of exploration. Interest to repeat the class remains high. Topics such as hemp-lime, mycelium and more non-conventional biomaterials are of high interest due to their novelty. Whereas wood and traditional fiber sources have very dedicated and entrenched industries, more novel biomaterials are perceived as opportunities for entrepreneurial growth and a flatter corporate structure. This flatter corporate structure, which is more relaxed, appears more accessible to current students. There also seems to be a stigma that larger forest products companies often do more harm than good for the environment and do not represent significant efforts to improve the environment while creating products. Entrepreneurial opportunities and flatter corporate structure give students the hope that they can impact their corporate environmental footprint quickly and meaningfully.

3.3 Experiential format is attractive, but has drawbacks

While EL remains very popular in pedagogical circles, there is a significant time and energy commitment needed to create meaningful EL opportunities for students. There is a significant amount of preparation needed to create and lead students through these experiences versus traditional format classes. Experiential learning often requires more resources and time due to the reliance on specialized materials or substances. Open pedagogical activities such as a flipped classroom or student-directed learning require a greater range of preparedness, where faculty need to anticipate the direction of student thought, rather than steer students through a curriculum.

Student learning methods also have an impact upon EL activities. Many students in the Sustainable Biomaterials curriculum would describe themselves as tactile learners, so the use of EL manifests itself as more hands-on activities – students making hemp-lime in the laboratory, visiting local companies, interacting with professionals in meaningful ways. Obtaining materials and using lab space carry real costs that are often not accounted for in teaching allowance.

The use of project-based learning also has drawbacks as well. Often, the specific materials and test activities are not the main teaching element. Students also need to understand the importance of the process of conducting longer-term projects. From our experience, the most successful projects conducted in these classes include a large number of student milestones similar to Table 2. While the structure may seem excessive, the structure becomes most useful in the event of unexpected activities or challenges, where the project structure can help students re-orient themselves and adapt to new situations while maintaining the timeline.

3.4 Developing focus for class—multiple materials or a single material?

The authors created the class “Mycelium and Hemp” with the intent that multiple materials would increase student learning about sustainable plant-based products in general. This was not an incorrect strategy, but in retrospect, the authors should have more carefully interrogated their own desires for the class.

As a faculty member is creating a class on novel materials, an important question to ask is the need for breadth versus depth of knowledge. Breadth of knowledge would be less technical-focused discussions and more comparative methods for different materials. Depth of knowledge would focus on more technical aspects and individual aspects of a single material. For the development of classes focused on novel materials, it is especially important to clearly elucidate educational goals.

Thinking more broadly about the spectrum of biomaterials available – wood, industrial hemp, bamboo, mycelium, straw, sheep’s wool, etc. – there are differences in these materials related to the current level of available knowledge and research. These materials could be placed on a continuum of different levels of knowledge. This continuum is offered to demonstrate the connection between relative material knowledge and the optimal pedagogical methods to transfer that knowledge.

- Wood, wood composite products, and bamboo have a high level of knowledge available, and many classes and curriculums (similar to Sustainable Biomaterials) can be constructed around them. There is also a high level of building code knowledge, which is a rigid system of product use. Teaching methods for this material can vary from lecture-style to EL and research-based systems. However, EL and research projects tend to focus more on specific applications or uses.
- Industrial hemp has a moderate amount of knowledge related to product use. Recently, hemp-lime material was introduced as an appendix to the International Residential Code (IRC) [International Code Council (ICC), 2024]. Teaching methods for industrial hemp may best be represented as a mix of lecture and project-learning methods, similar to the Mycelium and Hemp class we discussed, since there is some more generalized content, but still many opportunities available for product use. A strict lecture approach to this topic is not encouraged due to the current limits of product use and understanding.
- Mycelium, straw and sheep’s wool have a lower level of knowledge available. These products are not readily codified by the building code, and these materials vary greatly in the quality and application (i.e., different strains of mycelium for different product applications, different quality of straw and sheep’s wool depending upon various cultivars or breeds). These materials may lend themselves better to research-based or entirely project-based learning. Again, a lecture-based approach may not be the best method for information transfer due to the lack of uniformity of many products and materials.

3.5 Industry involvement is key

The real success of this class was due to the response from guest speakers who were willing to lead tours or contribute their time to speaking with the students. Many of these speakers gave a current and realistic view of the industry, sometimes in less than perfect light, and were not afraid to discuss issues and inform students of challenges. This honesty is often hard to find, but is needed in the area of developing new products. The authors have encountered many students who have unrealistic visions of product use, which are often difficult to temper.

Visits to farm sites, processors and sales points are desirable but not always feasible. When travel was not possible, the use of Zoom facilities which allowed for audio and video communication were highly valuable, and able to place the guest speakers in the student’s space. The authors are immensely grateful for all of the guest speakers – in-person and virtual – who contributed to this class. Specific activities included:

- A farm site visit to observe hemp plantings and CBD operations at Pure Shenandoah.
- Various industry organizations can serve to give an understanding of industry trends and current policy methods. In particular, our class used the U. S. Hemp Building Association, and the Virginia Hemp Coalition who joined our discussions via Zoom.
- Americhanvre is a company who uses a blown-in process to install hemp-lime material. Located in Pennsylvania, experts were able to join us via Zoom.

3.6 Using the EL method presented to investigate industrial hemp or other ABMs

The continued development of industrial hemp and other ABMs relies upon innovation and exposure of young building industry professionals to these products. Universities play an important role in inspiring and promoting the larger variety of available building materials throughout the industry. While Virginia Tech as an institution has several advantages such as agricultural researchers growing hemp, and the space available in the Department of Sustainable Biomaterials, there are opportunities to create similar experiential learning experiences that have been described here.

A distinct advantage of industrial hemp uses, and hemp-lime construction is that no specialized equipment is required for production. Given appropriate gloves, mixing can be performed with your hands if no other equipment is available. This contrasts with mycelium or similar materials, which require sterilization and higher cleanliness levels for processing.

Hemp-lime projects also have a very favorable scaling element. The sizes of samples constructed in Figure 1 were relatively small, while other universities and groups have conducted building-sized projects. The scalability makes hemp-lime very approachable and makes even small projects valuable in understanding the production method.

The authors also feel strongly that the success of courses related to industrial hemp or other ABMs should rely strongly on EL principles and theory. Typically, courses should begin with students reflecting on current literature sources and conversations with experts. Students can then begin to conceptualize their ideas of how to best use industrial hemp products and ABMs and then experience the use of materials through expert meetings and field trips. At this time, students can begin to craft projects which form the action portion of the learning activities. Finally, through the presentation of results and reporting, students reflect upon their experience and continue to refine their knowledge and views of industrial hemp and ABMs.

4 Conclusion

The origins of our teaching industrial hemp were inspired by students' interest in hemp as a material, a renewed interest by the public and existing entrepreneurs in growing and using hemp and growing markets for a variety of hemp-based products. While there has been limited experience in teaching about hemp products, we found success with the incorporation of EL methods combined with occasional lectures. Our visits with hemp product firms and those in building and construction sector confirm that project-centered, experience-based learning is desirable for them. Many of the graduates have gone on to seek employment in hemp production or graduate studies focused on hemp related topics. Student perceptions were positive and many enjoyed engaging with the material. Perceptions by the authors discussed some of the pertinent issues to address in class, including the issues of industrial hemp vs. cannabis, crafting courses which address and cultivate student interest, realizing the time and physical needs of EL versus traditional classroom activities, creating pedagogical activities appropriate to the level of knowledge available, and engaging industrial partners. Future uses of this format are encouraged for developing materials and products, where more standard lecture information may not be available.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The results of the student perceptions of learning (SPOT) survey conducted after Virginia Tech are shown in Table 3. This data was presented anonymously to the instructors after all grading was concluded. Before using this data, the authors conducted a preliminary query with the Internal Review Board (IRB) of Virginia Tech. Because of the previous anonymization of the data, no human subjects' permissions were needed.

Author contributions

DH: Writing – original draft, Writing – review & editing. TH: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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