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The development of a bioenergy-based green chemistry curriculum for high schools

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Abstract:
The Next-Generation Science Standards represent a major shift from learning science content to preparing students to become scientifically literate through inquiry and investigation. This article summarizes the unique opportunities available to develop a biotechnology laboratory course on biofuels that heavily emphasizes scientific practices in a high-school agriscience department in Wisconsin. Through collaborations with universities, federal research facilities, and the surrounding community, students were able to engage in rigorous learning experiences in a sociocultural setting in a manner that maximized their preparation for college and sustainable careers. This example also highlights how effective science teacher professional development and collaboration can allow for improved instructional opportunities in science education while also enabling positive contributions to ongoing scientific research.

Keywords: inquiry, sustainability, biotechnology, bioenergy, agriscience, NGSS, professional development

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1 Introduction

With the release of the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* [1] in 2012, science education has been increasingly portrayed as crucial to meeting many of our society's most pressing challenges. The Next-Generation Science Standards (NGSS) [2], which were based on the NRC's *Framework*, incorporate this same view of science education as a means for preparing students to take on the socioscientific challenges that await them throughout the rest of their lives. NGSS reflects a shift from recalling scientific facts to using scientific ideas and practices as tools for reasoning and making sense of the world. From the viewpoint of NGSS, science literacy and sense-making represent the primary goals of science education [3]. These goals require forms of science instruction that enable students to engage with the world around them, develop models to explain natural phenomena, test and refine their conceptual understanding through inquiry, and foster their sense of wonder in a manner that engenders a lifelong commitment to using valid evidence as the primary means of making decisions [4].

The practice of teaching secondary science has been continuously shaped by the ongoing and sometimes tumultuous debates about the roles and purposes of science education in American high schools. The theories, publications, and debates that helped to cultivate the creation of NGSS also guided and shaped the efforts of individual teachers as they reformed their own practice to keep up with a rapidly evolving profession. This chapter will provide a summary of experiences in developing a sociocultural science curriculum designed to engage students in science and engineering practices through a bioenergy-based green chemistry curriculum. Through partnerships with federal research centers, university campuses, teacher professional associations, and local businesses and community members, high-school students were provided with a unique classroom experience that combined inquiry-based laboratory learning with career shadowing experiences in a manner that encouraged the adoption of sustainable knowledge and practices in students' personal lives and future professions.

2 Overview of high-school agricultural education

The anecdotes that frame this chapter are unique in that they pertain to experiences that occurred in an agricultural sciences program (or agriscience program). Agricultural education has been officially recognized as a distinct secondary school subject in American education since 1917. While its original purpose was primarily to prepare future farmers to adopt scientific practices and new technologies, agricultural education has since

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evolved to reflect a much broader emphasis across all branches of the sciences. This subject now provides rigorous college and career preparation for more than 300 science-based professional pathways ranging from veterinary medicine to genetic engineering to environmental research. Today, there are roughly 12,000 agricultural education programs in the United States enrolling approximately one million students [5].

Instruction in agricultural education is comprised of three interconnecting components – inquiry-based classroom and laboratory instruction; experiential learning through community-based service and career experiences; and leadership education as delivered through involvement in student career-based organizations [6]. This approach, generally known as the "Three Circle Model of Agricultural Education," is highly reflective of sociocultural theories in education such as Lave and Wenger's situated learning and legitimate peripheral participation. These theories stipulate that learning is a process of gaining peripheral experiences in a particular community of practice that eventually build, expand, and develop into expertise in that specific content area [7].

2.1 National Agriculture, Food, and Natural Resources academic standards

The National Agriculture, Food, and Natural Resources (AFNR) Academic Standards reflect college-level content that is aligned to the NGSS. These standards utilize an organizational structure that encourages application and mastery of science content by students in agricultural courses. Instruction in agricultural science courses is typically offered by elective course options in US high schools with a certified agricultural instructor. These courses are often aligned to science standards and can result in science equivalency credit for students. While the specific content and titles of agricultural courses can vary, the contents of these courses are generally designed to align to the 8 "career pathways" found in the national AFNR academic standards. Examples of these pathways include animal systems, plant science, and natural resources [10].

Biotechnology represents one of the eight career pathways in the AFNR standards. This is a broad career pathway that encompasses a wide range of science- and research-based topics, including genetic engineering, microbiology, fermentation, enzymology, CRISPR, and more. The course on which this paper is focused was aligned to the biotechnology pathway. It served as a unique opportunity to create an entirely new interdisciplinary course focused on the interrelationships among physics, chemistry, biology, and ecology in a manner the reflected the changing ideals and expectations of secondary science instruction.

3 Bioenergy and biotechnology – upper level high-school agriscience

The course that serves as the focus of this chapter was developed for the Agricultural Sciences Department at Waterford Union High School in Waterford, Wisconsin. This is a small, semi-rural village of 5,000 residents about 30 miles southwest of Milwaukee. The high school enrolls about 1,000 students in grades 9–12. The Agricultural Sciences Department consists of 13 different courses focused primarily on the application of science to agricultural and natural resources systems. As one of these course options, the Bioenergy & Biotechnology (AGR 310) course has been offered annually at Waterford Union High School since 2010. The Biotechnology and Bioenergy course enrolled a maximum of 24 students. This course (which was usually abbreviated as just "Biotech" by students and staff) was offered during the spring semester over an 18-week period followed by a 120-min final exam session. Each week consisted of five 47-minute class periods. The Biotech course was open to students ranging from sophomores to seniors who had completed the prerequisite of the introductory Agriscience course (or who had a sufficiently strong background in chemistry and in conducting scientific laboratory work). Students who enrolled in the course typically had a strong background in science or mechanics, and had an interest in laboratory research, engineering, and/or environmental sustainability.

The Agricultural Sciences Department at Waterford Union High School had relatively large and modern facilities due to a school expansion that resulted from a surge in the local population several years prior. The main classroom had a capacity for 24 students and was supplemented with an adjacent laboratory room with six student stations as well as a greenhouse and office. Each laboratory station was managed by a paid student intern (supported with donations from local businesses) who also prepared the materials in advance for each week's laboratory.

3.1 Course outline

The course utilized five major units: The Basics of Fuel (including combustion chemistry, sustainability, and life-cycle assessment), Biodiesel (via transesterification), Fermentation and Ethanol, Bioprospecting and Enzymes, and Biogas. Each unit consisted of 3–6 weeks of instruction. A weekly breakdown of the units is shown below:

1. Introduction, Laboratory Safety, Intro to the Supervised Career Experience portfolio.
2. Basics of Fuel
   a. Chemistry of Fuel (thermodynamics, combustion chemistry, bond energies, entropy, enthalpy).
   b. Life-Cycle Assessment (assessing the economic, ecological, and social sustainability of fuel options).
3. Biodiesel
   a. Biodiesel (combustion engines, transesterification reactions).
   b. Biodiesel from Waste Vegetable Oil Laboratory
   c. Biodiesel Challenge Laboratory (group competition to create the highest quality biodiesel from the poorest quality used vegetable oil).
4. Fermentation and Ethanol
   a. Introduction to Ethanol (history of fuel use in the United States, fermentation, octane ratings, energy balances, emissions testing).
   b. Cellulosic Ethanol (carbon cycling, plant cellular biology, basics of fermentation).
   c. Fermentation (cell biology, respiration vs. fermentation, glycolysis, electron transport, biochemical pathways of fermentation, chemical properties of alcohol).
   d. Ethanol Challenge (group competition to develop and test fermentation protocols)
   e. Completion of Ethanol Challenge and Midterm Exam
   f. Cellulosic Ethanol Challenge (group competition to develop and test fermentation protocols for cellulosic sources of ethanol)
5. Bioprospecting and Enzymes
   a. Bioprospecting (enzymatic chemical reactions, enzyme structure and function, active site, polymers vs. monomers, cellulase biochemical pathway).
   b. Bioprospecting Challenge (series of group challenges to find and measure sources of enzymes for fuel and food production).
   c. Genetic Modification (genetic engineering, PCR, CRISPR)
   d. GMO Challenge (identification of genetically modified ingredients in foods via PCR).
6. Biogas (production of natural gas fuel via methanogenic bacterial anaerobic degradation).
7. Final Exams
   a. Presentation of Career Portfolios and Open-Note Essay Exam
   b. Final Exam (closed book, multiple choice)

3.2 Overall course format

No textbook was utilized for this course for multiple reasons. First, the pedagogical effectiveness of standard textbooks is questionable, especially in a high-school course with mixed abilities where the use of textbooks can result in achievement gaps. Second, the content of the course was based on the most advanced breaking research in the field. As some content in the course reflected research that had only just been published, a textbook would not lend itself well for this instructional approach to teaching science, nor would it reflect the new expectations of both the NGSS and the new AFNR academic standards. Due to the fact that the course instructor had personal experience in biofuels research at the university and federal level and had served as a content expert for the national academic standards for this subject, it was feasible for the curriculum to be written by the course instructor in collaboration with researchers and staff in nearby federal research facilities on the University of Wisconsin campus in Madison, WI. The curriculum as it was taught can be viewed at wuhsag.weebly.com (use the ”Classes” tab to find the course under ”Spring 2016”).

The focus of the Biotech course was primarily on providing students with a means to think about the nature of energy and to assess options for fuel in regard to their benefits and opportunity costs for societies and natural ecosystems. Students were introduced to the notion of energy by investigating how and why some substances burn but others do not. This was followed by a discussion about the concept of sustainability and its three primary considerations: social, economic, and ecological impacts. Students were guided to consider not just underlying chemical causes for the energy content of a fuel, but also the net gain or loss of energy as the fuel is acquired, refined, and utilized. Students were also guided in considering additional ramifications and externalities of each fuel choice, including the ecological and health impacts of pollution, whether a fuel increases or reduces social disparities, and whether an option for fuel would require dramatic shifts in infrastructure and societal norms. Overall, students used three primary considerations to assess the value of a fuel option: (1) Is it sufficient?, (2) Is it efficient?, and (3) Is it sustainable? Students used this framework to assess fossil fuels, biodiesel, ethanol, biogas, electrical transportation, and hydrogen fuel cells.

During this introductory general overview, the concepts of energy conservation, entropy, and enthalpy were heavily emphasized as a means to help students understand how and why a substance combusts. High-school students have a wide range of beliefs and interpretations of what actually happens to the matter and energy of a substance when it is combusted. The focus of this introductory portion was to help students to appreciate the relationship between bond energies and the potential value of a fuel. By explaining enthalpy as a kind of “leftover energy” as the atoms of the reactant molecules are rearranged into the product molecules, students not only had a heuristic for determining why some fuels result in the release of more energy than others but also had a means for tracing matter and energy as they are conserved across reactions (dispelling the notion that matter and energy are “used up” during combustion). This is a crucial consideration as students move into a discussion on sustainability because it helps them to better engage in the life-cycle assessment of a fuel. It also helps them to appreciate how and why carbon dioxide is produced during combustion. When students comprehend that any combustion of a carbon-based molecule results in the production of a heat-retaining gas, they can better appreciate the link between climate change and human activity.

After this general overview of the major options for fuel, students spent the remainder of the semester investigating three of the primary biofuel options: biodiesel, ethanol, and biogas. Each fuel type provided a means for discussing various topics in chemistry. In the biodiesel unit, the reactions that occur during the transesterification transformation of highly branched oil molecules into straight hydrocarbon chains become the emphasis. This is then tied to the combustion reaction and the rearrangement of hydrocarbon chains and oxygen molecules into carbon dioxide and water. Students are introduced to the concept of complete vs. incomplete combustion and observe how incompletely combusted products relate to smoke and pollutants commonly found in diesel exhaust. Students also consider how catalysts used in the transesterification process as well as the necessary step of heating relate to the final reaction rate as they are producing biodiesel. While students are in the laboratory, they also learn valuable laboratory practices, including the proper use of equipment, the process of titration, and keeping records in a laboratory notebook.

In the ethanol unit, students are introduced to the chemical processes inherent in fermentation. They consider how the properties of corn ethanol compare to gasoline, and use matter and energy tracing to assess the benefits and limitations of this renewable fuel option before exploring the fermentation reaction in more detail. They consider the potential benefits of cellulosic ethanol (particularly in regard to CO_2 and carbon cycling) and why this type of ethanol is exceptionally challenging to produce. This inevitably leads into a discussion on the nature of enzymatic reactions and how they relate to biology. Students are guided to see enzymes as crucial for living organisms due to their reduction of the activation energy of biochemical reactions. Using a yogurt production laboratory to showcase the lactase enzyme’s action on the breakdown of the lactose molecule, students are guided as they apply this model reaction to more complex reactions, particularly the breakdown of cellulosic polymers into simple glucose monomers that can be fermented into fuel ethanol. This opportunity is also used to provide students with explicit instruction on how the human body is affected by alcohol (particularly the different structures of the brain) and how the body enzymatic pathways for processing alcohol result in many of the visible signs of inebriation and recovery. By removing the mystique of alcohol consumption and portraying inebriation as merely the outcome of the body’s method for responding to and removing toxins from the body, the intent is to reduce its allure among teenagers.

After a unit on genetic modification as it pertains to enzyme production, the course concludes with a brief discussion about the methanogenesis reactions used to produce biogas in a methane waste digester. Students are once again introduced to the concept of greenhouse gases and are guided in comparing the much greater greenhouse effect of methane gas in comparison to CO_2.

3.3 Weekly course format

In the first weeks of instruction in each unit, the course adopted a consistent weekly schedule. Weekly topics would be introduced on Mondays using group- and whole-class discussions. This enabled students to practice sound scientific argumentation from evidence as a means to develop deeper scientific literacy. Students were provided independent work time on Tuesdays to work individually or in small groups to learn the core content for that week. Students were provided with printouts of detailed notes specific to the content of the week. They were also given guided worksheets that helped them to grasp content and understand that content in a deep, comprehensive fashion through the use of specifically tailored questions that helped to reveal connections and themes across the content. The instructor used this time to move from group to group as they worked to provide individual assistance or instruction as needed.

On Wednesdays, students were asked to demonstrate their knowledge in inquiry-based laboratories. Each laboratory was scaffolded in a manner reflective of the Vygotskian Zone of Proximal Development, which stipulates that instruction should be structured in a manner that allows students to engage and utilize knowledge and practices that are still in the process of maturing [9]. The laboratory packets prompted small student groups to independently form hypotheses, justify the hypothesis with a rationale, run the experimental protocol, collect data, and use the data to accept or reject their hypothesis. Follow-up questions were provided to allow the students to form direct connections with the content and classroom discussion at the end of the laboratory. On Thursdays, students were provided a time for group quiz preparation. This was followed by an opportunity for class Q&A, after which students individually took a 20- to 30-question multiple-choice quiz which was immediately graded in class. This immediate feedback proved to be crucial for student improvement and became a standard formative assessment in the course, allowing the effectiveness of each week's instruction to be assessed and to allow for any follow-up instruction where needed.

Fridays were reserved for career preparation or for classroom management. Students would begin each semester by choosing a career related in some way to the course content. Guided by a scaffolded packet and using statistics from the US Bureau of Labor and other sources, students would profile their potential future career. They would develop a path from their current point in high school through college to a successful start in that career. They would identify a postsecondary option for obtaining a necessary degree, choose a major, and even calculate their potential debt based on the average pay of the career in comparison to the tuition of the school. When needed, Fridays could also be utilized to re-teach concepts in the event that a large portion of the class did poorly on the quiz, to provide additional work time if needed for a laboratory or for notes, or to meet with students individually to discuss any concerns related to their performance.

Once students had mastered the content for a given unit, the Monday through Friday schedule was temporarily put aside in order to allow students to spend at least a week on a project-based summative assessment. At this point, the work of the instructor was almost entirely supervisory, with students being responsible for planning their laboratory protocols, collecting and analyzing their data, reaching their conclusions, and formally presenting their findings.

3.4 Modes of assessment

Students in the Biotech class were assessed based on their completion of their notes (20 %), weekly quizzes (30 %), unit exams (20 %), labs (10 %), final exam (10 %), and their career portfolio (10 %). The heavy grading emphasis on notes and weekly quizzes helped to ensure that students were encouraged to complete the day-to-day considerations. This foundational knowledge was heavily emphasized because it was vital to the more meaningful learning and comprehension that occurred in later units and in summative projects. Because grades were more determined by the foundational learning, there was more freedom to engage students in authentic assessments that were more like what would occur in a real-world laboratory or career-based situation without students fearing about a poor grade if their investigations did not go as expected. This also allowed the instructor to work more closely with students who had demonstrated that they were not prepared for these more advanced (and "more fun") tasks as their classmates were engaged in independent inquiry. This approach to instruction was essentially an effective compromise between the idealistic goals of inquiry-based science instruction that results in scientific literacy and the realities of teaching in a public grade school where grades are an unavoidable obligation for every instructor.

Notes were graded primarily on a completion basis. Students could receive a "plus" (100 %), a "check" (80 %), or a "minus," which resulted in a grade of 0 % until their notes were resubmitted for re-grading and a reduced late score. This was meant to prepare students for the expectations of real-world professionalism (i. e. do not submit something that is incomplete or poorly developed; no one pays for 50 % of a heart surgery).

While multiple types of weekly formative assessments were utilized (quizzes, self-reflections, discussions, group challenges, bell-ringers, etc.), the most in-depth assessments of student knowledge occurred during the group long-term laboratories at the end of each unit. These laboratories were designed to prompt students to connect their real-world laboratory experiences to specific concepts that they learned in the classroom. During group presentations on the final day, students were asked pointed questions to check for comprehension and assess their ability to relate their findings to broader connections across the course content.

While the district expectations left few options other than a multiple-choice format for the final exam, students were given an "extra" final exam during the last week of instruction. In this essay/short answer exam, students were provided with 4 days to work in teams to respond to questions that reflected the "big ideas" of the course. Questions ranged from why it is so difficult to produce cellulosic ethanol, to what actually happens to molecules and energy in a log when it is burned, to outlining a plan for US energy independence over the next five decades based on critiques of existing fuel options. Students were asked to address the questions in a presentation format that they would deliver in small groups on the final day of class, and these presentations were graded using a rubric based on accuracy, thoroughness, professionalism, full group involvement, and effort.

3.5 Supervised Career Experience portfolios

A key aspect of the mission of the Agricultural Sciences Department is to maximize readiness for college and for careers. As such, each student was required to complete a standardized Supervised Career Experience portfolio and present this portfolio in an exit interview during the final week of the semester. In these presentations, students had to outline their future college and career intentions; show how they obtained 15 hours of relevant career experiences with professionals in relevant careers from the surrounding community; provide evidence of their experiences in the form of pictures, reviews from the professionals they shadowed, and personal journaling; and relate these experiences to their eventual college and career path. These career portfolios proved to be incredibly impactful for students. In addition to providing students with the means to chart a clear educational and career trajectory for their future, the mandatory career experiences also helped them to see the relevance of the course material to their own personal lives and allowed them to determine whether or not a given career interest was appropriate given their preferences and abilities. This is reflective of learning as described by Lave & Wenger [7] in that it is more than just comprehending content – it is "becoming a full participant, a member, a kind of person."

3.6 Student reviews

While not required by the district, anonymous student reviews were utilized to assess the effectiveness of the instruction, identify areas for improvement to the course, and provide evidence for the effectiveness of the instruction to the district administrators. Of those who responded over 2 years ($n = 27$), 67 % ranked the class as "Better than most" or "Better than all" when compared to other courses in the school. Only one student ranked the course as below average overall. Almost three-fourths of students ranked the materials and instruction as more effective than average, with more than half (56 %) ranking it as "More Effective than Most" or "More Effective than All."

3.7 Facilities and funding

While the department had relatively new facilities that included a greenhouse and laboratory in addition to a classroom, the funding for high-school agriculture courses is generally limited due to the elective nature of the courses. The Biotechnology and Bioenergy course required extensive expansions to the collection of laboratory equipment, glassware, and facilities. While the content of this course was equivalent to what was offered at nearby colleges and universities, the department budget alone was quite insufficient to provide for these objectives.

Collaborations with researchers and staff at nearby universities proved to be crucial for enabling the course to occur, and a combination of ingenuity and inventiveness resulted in solutions that drastically lowered the costs of operations for this course. In lieu of the standard $800 fermenter devices for students in this subject area, the instructor collaborated with federal researchers to design an equally effective model that could be built for as little as $15 (the current design of this tabletop fermenter can be built for $40 and uses materials that are longer lasting and higher in quality). In lieu of expensive pre-packaged student kits from science supply companies, laboratory chemicals were purchased in bulk and prepared in advance by the instructor outside of standard instructional time. Later, this became the responsibility of a paid student laboratory manager. Ingenuity and a willingness to forgo convenience reduced the final cost of the class by thousands of dollars.

Donations also proved to be key for the implementation of this course. Waterford Union High School, being located in southern Wisconsin, was surrounded by a myriad of dairies, cheese factories, and food-processing companies. Each possessed an ample supply of laboratory equipment, and their donations of used equipment and glassware helped provide much-needed supplies. Educational grants also helped to cover gaps in the budget, allowing for the purchase of equipment that could not be obtained through donations. University resale stores proved to also be a convenient source of affordable but functional glassware that could feasibly be purchased out of pocket by the instructor.

After multiple years of successfully executing this Biotech course, the school's administrators were persuaded to reallocate thousands of dollars budgeted for textbooks for the purchase and installation of new laboratory benches and safety equipment. A one-time sizable earmark in the annual department budget provided for the installation of six modern laboratory stations, overhead electrical, secure chemical storage in the laboratory itself, and a new exhaust system. The laboratory stations were installed by the instructor in exchange for hourly pay to avoid higher costs that would have occurred had the installation been performed by company from which they were purchased.

Finally, local businesses provided annual donations to support a student internship program in the department as part of its mission to maximize student readiness for college and for careers. A minimum of seven student internship positions were supported through a combination of these donations and various fundraisers. These internship positions ranged from management of the department greenhouse to running the department's student office to serving as the laboratory manager who prepared the materials for each laboratory in each class on a weekly basis. Students who successfully completed the internships were provided a scholarship at a percentage rate determined by their quarterly performance evaluations.

4 Great Lakes Bioenergy Research Center and the creation of the biotechnology and bioenergy course

While a myriad of factors led to the creation of the Biotechnology and Bioenergy course at Waterford Union High School, the most impactful influence was from the Great Lakes Bioenergy Research Center (GLBRC) on the University of Wisconsin – Madison and the Michigan State University campuses. GLBRC is one of three Bioenergy Research Centers in the United State Department of Energy and is the only one that is based at an academic institution. In addition to its research, the GLBRC has an Education and Outreach group whose focus is to "enhance the broad understanding of contemporary issues in bioenergy" in order to "create a scientifically literate citizenry"[10].

Much of the emphasis of GLBRC Education and Outreach is focused on enabling K-12 instructors to both improve their ability to deliver science instruction while also providing bioenergy-related materials and curricular options free of charge to instructors. The instructor for the Biotech course began his involvement with GLBRC in 2010 when he attended the first-ever Bioenergy Institute for Educators. This 2-week national professional development opportunity was held on the University of Wisconsin campus and provided a crash course on bioenergy, sustainability, agronomy, and engineering while providing attendees with direct experiences with the scientists conducting the research in these areas. Participating educators were also provided with an opportunity to develop curriculum and instruction with the Education and Outreach staff, with the feedback from this partnership guiding their understanding of how to most effectively develop scientific literacy among their students.

4.1 Research Experiences for Teachers (RET)

In addition to the Bioenergy Institute, the GLBRC also provides Research Experiences for Teachers (RETs). Through the RET opportunities, teachers work side by side with federal researchers over an extended period of time to learn more about a particular research area while developing curriculum specific to that field. In 2011, Waterford's Biotech course instructor was provided with a RET opportunity in the bioprospecting laboratories of Dr. Cameron Currie at GLBRC. Through the RET opportunity, the course instructor was provided with a stipend to work in the Currie laboratory on the University of Wisconsin campus for 6 weeks. Dr. Currie and his staff research enzyme production of various microbes and identify how the interactions of microbes and other organisms can be symbiotically sustained.

Prior to this joint experience, the bioprospecting assay used by the Currie laboratory for microbial enzyme activity involved expensive media and a series of complex laboratory procedures that left little room for error (which presents significant obstacles for reproducing this work in a high-school chemistry laboratory setting).

After completing a chemical analysis of their media, an equally effective microbial media was developed using only Miracle Grow fertilizer and tap water. By adding a sample of microbes to the Miracle Grow media solution in a test tube along with a strip of standard filter paper, the production of cellulose enzymes could be measured simply by recording if and when the strip of submerged filter paper had degraded. This ensured that high-school students could not only recreate the scientific practices of laboratories like Dr Currie's, but also contribute to their research through citizen-science and internet data sharing through Google Forms. Upon successfully developing and testing this simplified laboratory protocol, an accompanying curriculum was developed and professional development opportunities were made available for the purpose of training other teachers to use the protocol and curriculum.

4.2 TED-Ed & bioenergy

During this same time period, Waterford's agriscience instructor was offered the opportunity to work with TED (Technology, Engineering, and Design, as generally known from their "TED Talks") to create an online curriculum about bioenergy and bioprospecting based on his experiences in the Currie laboratory. TED was in the process of finding teachers who had utilized unique perspectives to teach in novel ways. The goal of this initiative was to pair these teachers with cartoonists and producers who would animate the lesson and create a 3-min online video. Students would have the opportunity to take an online multiple-choice assessment, engage in discussion boards, and share ideas and suggestions as part of an online community based around each lesson. This lesson has been viewed almost 50,000 times and has resulted in almost 4,000 questions and answers. The lesson can be viewed at https://ed.ted.com/lessons/biofuels-and-bioprospecting-for-beginners-craig-a-kohn [11].

5 Conclusion

Science teachers are increasingly being called on to teach in a manner that emphasizes the development of scientific literacy and enable students to use evidence and scientific practices to solve real-world problems. This is particularly true in recent years due to the expectations implicit in the NGSS. However, enabling teachers to adopt these new standards and expectations in their own classroom instructional practices can be challenging, as many teachers have not experienced this type of instruction firsthand and are rarely prepared to fully meet the expectations of new standards without considerable support.

Opportunities for professional development in the natural sciences from federal agencies, universities, and other scientific entities can provide a valuable means to shape and improve the instruction that students receive in secondary science. When these professional development opportunities are tied to outreach efforts, a participating teacher's impact can spread far beyond their own classroom.

In light of the social and political challenges faced by developed nations like the United States, it is increasingly imperative that we provide coherent, applicable, and well-designed professional development opportunities to science teachers in addition to new standards and curriculum. Improving the effectiveness of secondary science instruction through these methods will enable students to become scientifically literate citizens with a greater understanding of the need and means for a more sustainable society.

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