Restaino *et al. Fire Ecology* (2024) 20:62
https://doi.org/10.1186/s42408-024-00296-6

Fire Ecology

FORUM

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Taking the next step in wildfire education: integrating multiple knowledge forms into co-produced high school fire science curricula

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Abstract

The wildfire issue in the western United States presents a complex challenge that impacts both society and the environment. Implementing K-12 education programs focused on wildfire can play a significant role in addressing this issue. By integrating wildfire education into school curricula, teachers can equip students with the knowledge and skills needed to understand fire ecology, land management, and wildfire preparedness. Early exposure to wildfire science education can also connect students with viable career paths in fire and ecosystem management. We used our position as Cooperative Extension educators in Nevada's Living With Fire Program to catalyze fire science knowledge through creating a high school wildfire science curriculum that is focused on fire ecology, wildfire preparedness, and career exposure. We used a transdisciplinary approach to create educational materials that are effective, relevant, and accurately represent wildfire in Nevada. We integrated five different knowledge forms (technical, cultural, management, institutional, and student) to create a robust curriculum that includes many different stakeholder priorities and values, while still meeting the needs of students and teachers. Our initial impacts assessment demonstrates that our curriculum instruction is creating learning advances in fire ecology and wildfire preparedness. We assert that this curriculum and other wildfire education programs in our region can increase our overall capacity for living with fire.

Keywords Wildfire preparedness, K-12 education, Curriculum, Knowledge co-production, Transdisciplinary

Resumen

El tema de los incendios de vegetación en el oeste de los EEUU presenta un complejo desafío que impacta tanto a la sociedad como en el ambiente. La implementación de los Programas de Educación K12 enfocados hacia los incendios de vegetación pueden jugar un rol importante en el direccionamiento de este tema. Mediante la integración de programas de educación en el tema incendios en la currícula de las escuelas, los maestros pueden proporcionar a sus alumnos el conocimiento y las habilidades para entender la ecología del fuego, el manejo de las tierras, y la preparación para enfrentar eventos de incendio. La exposición temprana a la educación en la ciencia del fuego puede también conectar a los alumnos con caminos hacia carreras en la ciencia del fuego y el manejo de ecosistemas. Usamos nuestra posición como Educadores en Extensión Cooperativa en el programa de Nevada "Vivir

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con el Fuego" para catalizar el conocimiento de la ciencia el fuego a través de la creación de un curriculum de ciencias a nivel de escuela secundaria enfocado a la ecología del fuego, la preparación para los incendios, y la exposición de sus carreras. Usamos una aproximación transdisciplinaria para crear materiales que sean efectivos, relevantes, y que representen adecuadamente el tema del fuego en Nevada. Integramos cinco deferentes formas de conocimiento (técnico, cultural, de manejo, institucional y de estudiantes) para crear un currículum robusto que incluya muchas y diferentes prioridades y valores de los individuos interesados, y que alcancen también las necesidades de maestros y alumnos. Las determinaciones de nuestros impactos iniciales demuestran que la intención de nuestro currículum es la creación de avances tangibles en el conocimiento sobre la ecología del fuego y la preparación en caso de incendios. Afirmamos que este currículum y otros programas de educación en la región pueden incrementar nuestras capacidades para convivir con el fuego.

Introduction

The wildfire issue in the western United States presents a complex challenge that impacts both society and the environment. Addressing the issue requires a multifaceted approach that encompasses fire and land management, community preparedness, science-informed policies, and education (Charnley et al. 2020; Paveglio et al. 2016). By integrating wildfire education into school curricula, teachers can equip students with the knowledge and skills needed to understand fire ecology and management (Cox et al. 2019; Hahn and Truman 2015). Engaging youth with the issues and solutions of wildfire can empower the younger generation to become proactive change agents in their communities and improve community wildfire preparedness (Cox et al. 2019).

Understanding the unique challenges of wildfire in Nevada highlights the importance of developing K-12 curriculum specific to this region. Nevada ecology is uniquely complex due to the large ecological differences between Nevada's basins and ranges and the pervasive invasive grass-fire cycle that has substantially altered fire regimes (Fusco et al. 2019). Developing wildfire-focused curriculum can increase exposure to these complex problems and engage students with locally relevant phenomena, thus leading to a more fire-prepared public. K-12 curriculum can also be an effective driver of social change within communities if done effectively (Carroll Steward et al. 2023). Through working within existing education systems, wildfire preparedness messaging can be efficiently shared with a large population of students, and schools tend to be more representative of the total population's racial, ethnic, and economic demographic (Hahn and Truman 2015) than traditional wildfire preparedness outreach campaigns.

Developing an educated workforce is another critical part of tackling the wildland fire issue, especially in the rural West. Land management agencies are finding it increasingly difficult to recruit and retain a skilled workforce, creating challenges in implementing essential ecosystem management projects and effectively suppressing unwanted wildfires (Thompson et al. 2023). Early exposure to fire science education for K-12 students can connect classroom learning with viable career paths in fire and ecosystem management (Mekinda 2012; Thessin et al. 2017). By building a pipeline from education to employment, we can help address the workforce shortage and ensure a sustainable future for managing wildfires in the West.

As Cooperative Extension educators in Nevada's Living With Fire Program, we created a high school wildfire science curriculum that focuses on fire ecology, wildfire preparedness, and career exposure. We focused on high school because there are no existing Nevada-specific fire curricula and because many high school students are thinking about careers at this stage. We used an extensive stakeholder engagement process to co-produce lessons that incorporate diverse knowledge forms, are relevant to local ecology, align with Next Generation Science Standards (i.e., science standards implemented in most states in the US—https://www.nextgenscience.org/), and fit into existing course progressions. In so doing, we created a highly implementable and applied curriculum that fulfills needs in our region and brings scientific and technical knowledge to the public.

The wildfire science curriculum has four primary goals focused on increasing students:

1. Ecological literacy
2. Knowledge of community and individual wildfire preparedness
3. Understanding of fuels reduction treatments and other wildfire-mitigation actions
4. Awareness of the breadth of wildland fire-related career opportunities

Curriculum background and development

Using K-12 curriculum to drive positive changes in communities offers several advantages if done effectively. While K-12 programming has the potential to efficiently reach a population, there are many challenges and

constraints that come with creating materials that meet the needs of teachers and their students. These challenges are as follows:

1. Educational standards and testing requirements constrain teachers' autonomy (Ernst et al. 2018; Roblin et al. 2018).
2. K-12 education in Nevada public schools is comparatively underfunded (NEA Research 2024). The urban areas have very large class sizes and lack support for specialized content and rural populations in Nevada experience internet bandwidth issues.
3. Curriculum adoption is a high-effort, low-frequency task. Adopting a new curriculum takes significant effort and is not done by teachers lightly (Davis et al. 2016; Roblin et al. 2018).
4. The post-COVID education setting is challenging due to pandemic-era learning losses and teacher staffing shortages (Fisher et al. 2022, Golden et al. 2022).

Nevada teachers have relatively lower access to curriculum that features local ecological issues than peer teachers in other states. This is in part due to the many very rural areas in Nevada and less funding spent on education compared to other states (Waller and Bureau 2012). There are several existing wildfire educational programs and curricula currently used across the US (Ballard et al. 2012), but they are not tailored to Nevada's needs. These materials range from the prevention-focused messaging of Smokey Bear to other materials where wildfire preparedness and ecological literacy are the main goals. The most widely used wildfire science curriculum is the FireWorks curriculum developed by the US Forest Service Rocky Mountain Research Station (Smith et al. 2018). This curriculum contains a base package as well as six region-specific adaptations (Kline et al. 2018). While the FireWorks curriculum contains many engaging and effective activities, in early interviews teachers expressed a preference for a curriculum that was designed to align with a specific science course rather than an array of activities that the teacher must fit into their syllabi.

We used a transdisciplinary approach to create educational materials that are effective, relevant, and accurately represent wildfire in Nevada. A transdisciplinary approach is one that uses various knowledge forms, specifically integrating non-academic knowledge into the development of science products. Here we integrated a diverse knowledge set to create a robust curriculum that more adequately reflects the challenges and unique context of wildfire in Nevada. We utilized the following knowledge sources in our curriculum development process:

1. Technical knowledge—Scientists and journal articles provided an understanding of fire ecology, data sets, and relevant phenomena students could explore.
2. Cultural knowledge—Tribal members, ranchers, land managers, and community members provided insights that deepened this project's ecological and cultural understanding of wildfire.
3. Management knowledge—Fire professionals provided management knowledge to identify priority topics related to fire and land management.
4. Institutional knowledge—Teachers contributed information about what is effective in their classroom contexts.
5. Student knowledge—Interviews with students were used to gauge age-appropriate learning activities, ecological literacy, and common misconceptions about wildfire.

It is important to note that stakeholders could provide multiple types of knowledge and that there is significant overlap in the type of information that each group provided. For example, tribal members offered cultural knowledge, technical knowledge, and management knowledge about fire history, science, and management.

We divided the curriculum development process into three distinct phases: scoping, co-development, and delivery. During the scoping phase, we conducted a needs assessment to gain a better understanding of what type of educational materials were needed in Nevada. In the co-development phase, we worked with teachers to develop lessons that would support their course syllabi and were academically appropriate. Finally, in the delivery phase we provided teacher trainings and in-classroom support to assist teachers adopting the curriculum.

Phase 1: scoping

We interviewed stakeholders to determine the breadth and depth of topics needed for the curriculum (Fig. 1). We categorized stakeholders into two primary groups during the scoping phase: (1) technical experts—fire and land managers ($n=10$), scientists ($n=14$), tribal members ($n=8$), and community members ($n=16$), and (2) educational experts—educators ($n=40$), students ($n=12$), and education administrators ($n=8$). Interviewees were identified through existing connections and then via snowball sampling. We conducted 82 different 30 to 60-min informal interviews over 16 months. Interviews with the technical experts were conducted until we reached saturation (i.e., until we consistently heard no new ideas or concepts; Merriam and Tisdell 2016). The educational experts provided additional feedback on the curriculum in the co-development phase during peer review (see phase

Knowledge Forms	*Information Collected*
Scientists and Journal Articles	» Necessary wildfire ecology principles for students to learn » Example data sets and phenomenon that could be included in lessons » Role of invasive grasses in ecology of the Great Basin » Significance of loss of sagebrush and sagebrush habitat » Consequences of pinyon juniper encroachment » Impact of historical and use on current fire regimes » Need for management actions » Ecological need for wildfir
Tribal Members	» Offered perspectives of what youth should know about wildfire in Nevada » Emphasized the important relationship between land management and nature » Cultural context of loss of tribally managed wildfire in the Great Basin and loss of ancestors » Loss of human capacity needed to manage the lands » Lack of recognition of Traditional Ecological Knowledge (TEK) in land management actions » Request to include valuation of TEK alongside Western Scientific in curriculum
Fire and Land Managers	» Identified the need for wildfire preparedness education » Emphasized the need for wildfire and acknowledged that fire suppression is not the solution » Need to increase public understanding of the relationship between land management and ecosystem resilience to increase public acceptance for management » Need to expose and attract students to careers in wildfire » Cultural differences between the rural/urban divide in Nevada result in misconceptions about the relationship between humans and fire.
Educators	» Need for curriculum to be user-friendly ("plug and play") and aligned with existing course syllabi » Need to work within constraints of large (35+ student) class sizes with no prep period » Can not give homework » Want curriculum about local and engaging phenomena » Willing to spend class time on wildfire as they see it is an important subject for students » Trauma-informed teaching methods
Students	» Past experiences with wildfire education largely prevention focused (Smokey Bear) » Experience with wildfire preparedness was parent-led (i.e. students lacked their own agency) » Limited ecological literacy » Urban students percieved lower impacts of wildfire directly to them » 56% with a personal or familial past scary experience with wildfire » Concern for nature over humans - low perception of wildfire risk to themselves

Fig. 1 Stakeholder interviews resulted in a collection of information derived from multiple knowledge forms. This information formed the basis for the curriculum drafts that were shared with teachers in the co-development phase

2 for more details). Interviews with educational experts were conducted continuously throughout the curriculum scoping and co-development phases. Notes of main interview points were compared to identify common themes or tensions between interviewees. The most common tension within stakeholder input was accurately depicting nuanced ecological relationships and staying within the time constraints teachers had on instructional time. Several follow-up interviews between teachers and technical experts ensured that simplifications of content remained accurate.

We interviewed technical experts to (1) improve our understanding of wildfire ecology in Nevada (technical and cultural knowledge), (2) learn what information

students needed to decrease their wildfire risk in Nevada (management knowledge), and (3) compile a list of data sets, phenomena, and readings that could be featured in the curriculum (technical knowledge). With the educational experts, institutional knowledge was used to narrow down the list of technical concepts identified in previous interviews. We produced lesson outlines that were shown to the educators several times and continually incorporated feedback into newer lesson plans. Interviews were conducted over several months, so more developed lesson plans were shared with individuals that participated in later stages of the scoping phase. This gave us the opportunity to not fatigue the initial participants and still receive useful feedback to improve the design and structure of the curriculum.

The top priorities of technical experts were largely congruent despite some differences in the emphasis within those priorities (Fig. 1). Scientists' emphasized the positive invasive grass-wildfire feedback loop and the needed intervention to stop the rapid spread of invasive grasses. Fire and land managers shared that the public should learn about the ecological need for land management actions; public resistance to fuels reduction projects conducted by agencies is an impediment to completing projects. Tribal members sought to reframe this issue to emphasize that every action is a land management decision—that choosing not to manage a landscape has consequences. Each of these three groups shared that an ecological understanding of Nevada's historical and current fire regimes was a key priority for students because of the distinct fire ecology in the Great Basin.

From interviews with educational experts, we learned that educators (1) felt time pressure to cover many standards, concepts, and skills in a short amount of time, (2) wanted curricula that aligned with common science course syllabi and were user-friendly, (3) recognized the need for youth wildfire education, and (4) were enthusiastic about a Nevada-specific high school wildfire science curriculum. Based on the first two insights, we created outlines of week-long curriculum units designed around syllabi for three common science courses—biology, earth science, and environmental science. During additional educator interviews, they provided feedback on our outlines to help us better align the proposed curriculum units with course syllabi and required state science standards.

Phase 2: co-development

There is a broad spectrum of co-design methods used in curriculum development (Pieters et al. 2019). These range from teachers serving as the primary curriculum authors with support from collaborators to teachers providing feedback on materials written by collaborators. Based on teacher availability and COVID-era teacher shortages (Bill et al. 2022; Tang 2023), this curriculum used a co-design process where the materials were primarily written by us. During co-development, teachers piloted specific lessons, made revisions to draft curriculum, and provided feedback on each other's changes (Fig. 2). Scientists, fire and land managers, and tribal members provided feedback on the curriculum during a peer review process at the end of the co-development phase.

We employed our co-development process largely through teacher feedback sessions during the spring of 2022. We led a series of six, monthly sessions and a single-day intensive session with 19 different teachers. Teachers were compensated between $25 and $30 per hour, depending on the session format, for their participation in these feedback sessions. Teachers also received a free set of classroom science equipment required to conduct field activities included in these lessons (grant funding paid for equipment).

Several changes to the curriculum were made based on feedback during the co-development process. These included changes to make the curriculum (1) more easily understood by Nevada students and (2) meet the needs of post-pandemic learning and large class size. Each unit is designed to build students' ecological literacy and then culminate with students applying this knowledge to design a management solution or conduct critical analyses. Teachers expressed an interest to move away from digital learning after the pandemic, so we revised the curriculum to primarily be accessible with pencil and paper. In response to large teaching loads (>35 students per class), we emphasized learning through peer feedback rather than feedback only from teachers. These modifications responded to the needs of large classrooms and a student population that experienced pandemic-era learning challenges. It is more important now than ever to meet students and teachers where they are rather than expect them to integrate curriculum that was not built for their conditions.

Phase 3: delivery

The delivery phase focused on training and disseminating the curriculum to teachers, school districts, and other educators. We largely shared the curriculum through teacher trainings that differed from the co-development sessions in phase 2. We recruited teachers to join our training sessions and we compensated teachers with stipends ($25–30 per hour). We felt it was important to value the time and commitment of teachers and to treat these trainings as a professional development opportunity. The trainings were a mix of content education (i.e., teachers learning about fire science) and sharing the structure of the curriculum. We also

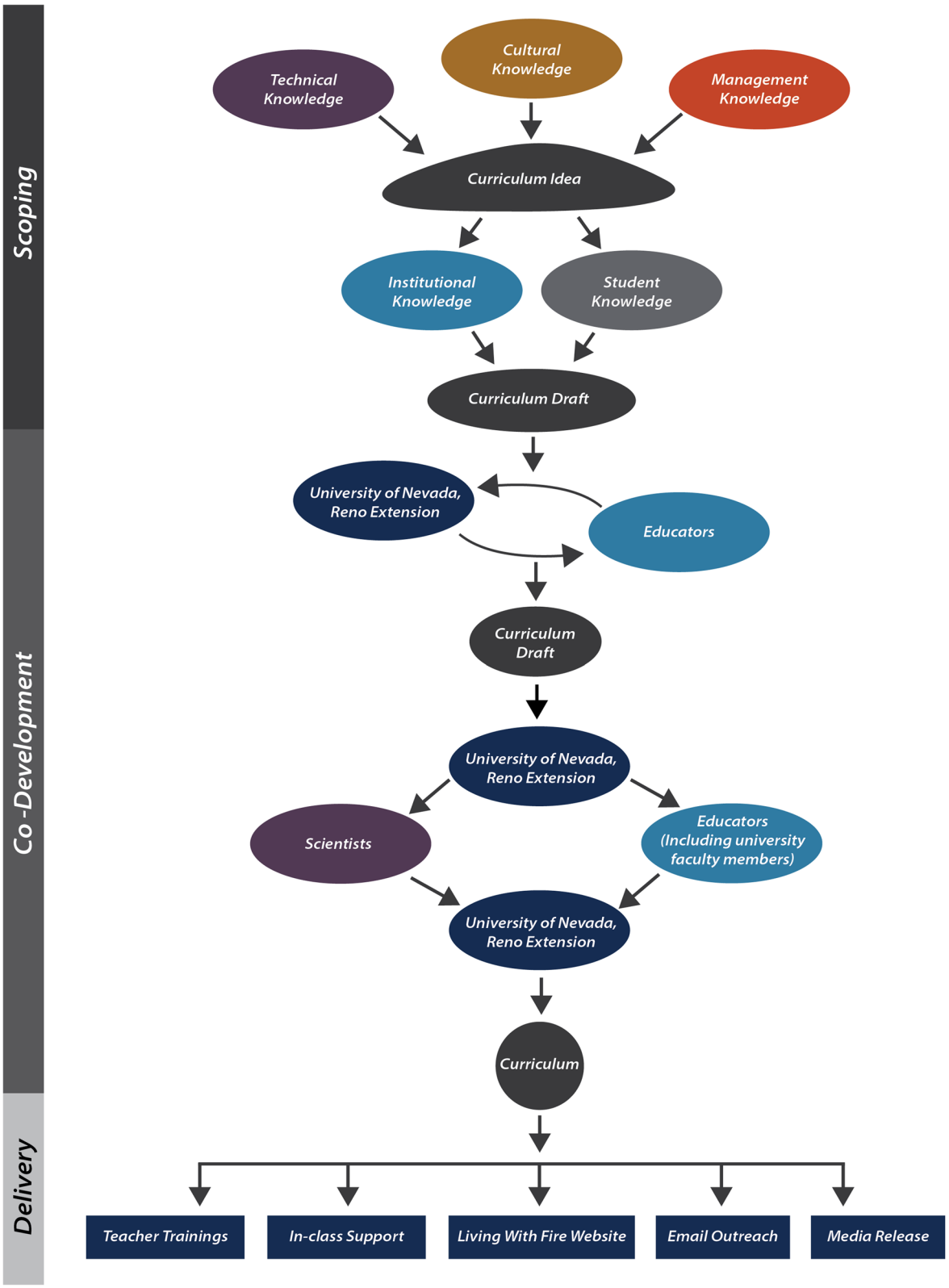

Fig. 2 The curriculum development was divided into three phases: scoping, co-development, and delivery. In the scoping phase, we integrated different knowledge forms into ideas that were then shared with teachers and students. The curriculum draft that resulted out of this phase then was reiterated with teachers, scientists, and educators to create our final draft. The curriculum was then distributed through teacher trainings, in-class support, and digital outreach

spent time workshopping how teachers could adjust the curriculum to their own unique circumstances such as field trip options and course syllabi. We offered the trainings in-person and virtually to accommodate teachers in rural Nevada.

The adoption of a new curriculum is a high-effort, low-frequency occurrence because teachers are generally overburdened with state standards and workloads (Davis et al. 2016; Ernst et al. 2018). Teachers in all three phases of this project listed in-person classroom support as a need for adopting a new curriculum. We provided support to teachers, including our staff teaching the curriculum and helping teachers adopt it on their own. Some teachers independently implemented the curriculum with only information from the teacher trainings. We provided a cache of equipment that teachers can borrow for field days to reduce barriers to hands-on and field-based activities.

Another critical part of delivering the curriculum was connecting professionals to the classroom. We wanted to expose students directly to the management experience that fire professionals have while highlighting potential career pathways. Examples of professionals that we brought to the classroom include firefighters, fire and land managers, and graduate students. Professionals were recruited through our existing relationships with fire agencies and asked to serve as subject matter experts in areas where their expertise overlapped with the curriculum. For example, a fuels specialist joined classes during the culminating project of the biology unit where students design a fuels mitigation project around a Nevada neighborhood.

The curriculum units are also available online at www.livingwithfire.org and are free. We shared the website with educators and through media releases.

Completed curriculum units

Based on teacher input, we completed three curriculum units: a biology unit (Eusden and Restaino 2023) on ecological impacts of wildfire and land management (9th grade), an earth science unit (Eusden and Restaino 2022a, b, Eusden and Restaino 2023) on wildfire and climate change and post-fire erosion (10th and 11th grade), and an environmental science unit (Eusden and Restaino in review) on past and future fire regimes (for 11th and 12th grade). We integrated different knowledge forms into each unit (Figs. 3, 4, and 5). All three units fulfilled many required standards for science education (Supplementary Materials).

The biology unit (Fig. 3) starts by familiarizing students with native and nonnative plants found in Nevada, then explores dynamics between wildfires, ecosystem carrying capacity, and biodiversity. This unit culminates with students designing a fuels reduction project for a Nevada neighborhood. The final assessment of the biology unit asks students to compare fire regimes under Washoe Tribe stewardship and during the contemporary period that is defined by European colonization and fire suppression. The only homework in the biology unit is a take home wildfire preparedness assignment with a list of 14 different preparedness actions including how to plan for evacuations, defensible space, and home hardening. Students are asked to complete 1–3 of these activities with their families over a week.

In the earth science unit (Fig. 4), students explore climate projections for Nevada and use these projections to create their own prediction of how wildfire will change in 2030–2060. Students then explore dynamics between wildfire severity, post-fire erosion, and nutrient cycling. This unit culminates with students designing an erosion mitigation plan for a historic Nevada wildfire of their choosing based on topographic and burn severity maps.

In the environmental science unit (Fig. 5), students explore how climate change and interannual weather variability impact fire regimes. The students use journal articles and webinars from the Great Basin Fire Science Exchange to design a research project proposal to better inform land management practices. Students then participate in a mock grant funding panel to evaluate each other's proposals. The unit ends by asking students to critically compare fire regimes in Nevada's high elevation sky islands with fire regimes at lower elevations.

Impacts

We have observed the curriculum in action through providing in-class instruction and have surveyed student knowledge of both fire ecology and their ability to prepare for wildfire. Since April 2023, the curriculum has been taught to 1200 students across northern Nevada. We have evaluated one cohort of high school freshman that received the biology unit but are anticipating more data in the coming academic year for biology, earth science, and environmental science. Our overall curriculum goals include not only increases in knowledge but also positive exposure to wildfire careers. It is unclear whether the 9th grade high school students are at an appropriate age for career exposure compared to the environmental science students that are in 12th grade.

In 2021, we delivered the biology curriculum to 645 students and assessed their learning through pre- and post-implementation surveys and interviews. In 2021, when a subsample of students ($n=111$) were asked to respond to the statement "I can do things to protect where I live from wildfire," students who responded "Strongly Agree" moved from 15 to 24% and 48 to 56% "Somewhat Agree." Following up in 2022, when students ($n=529$) were asked

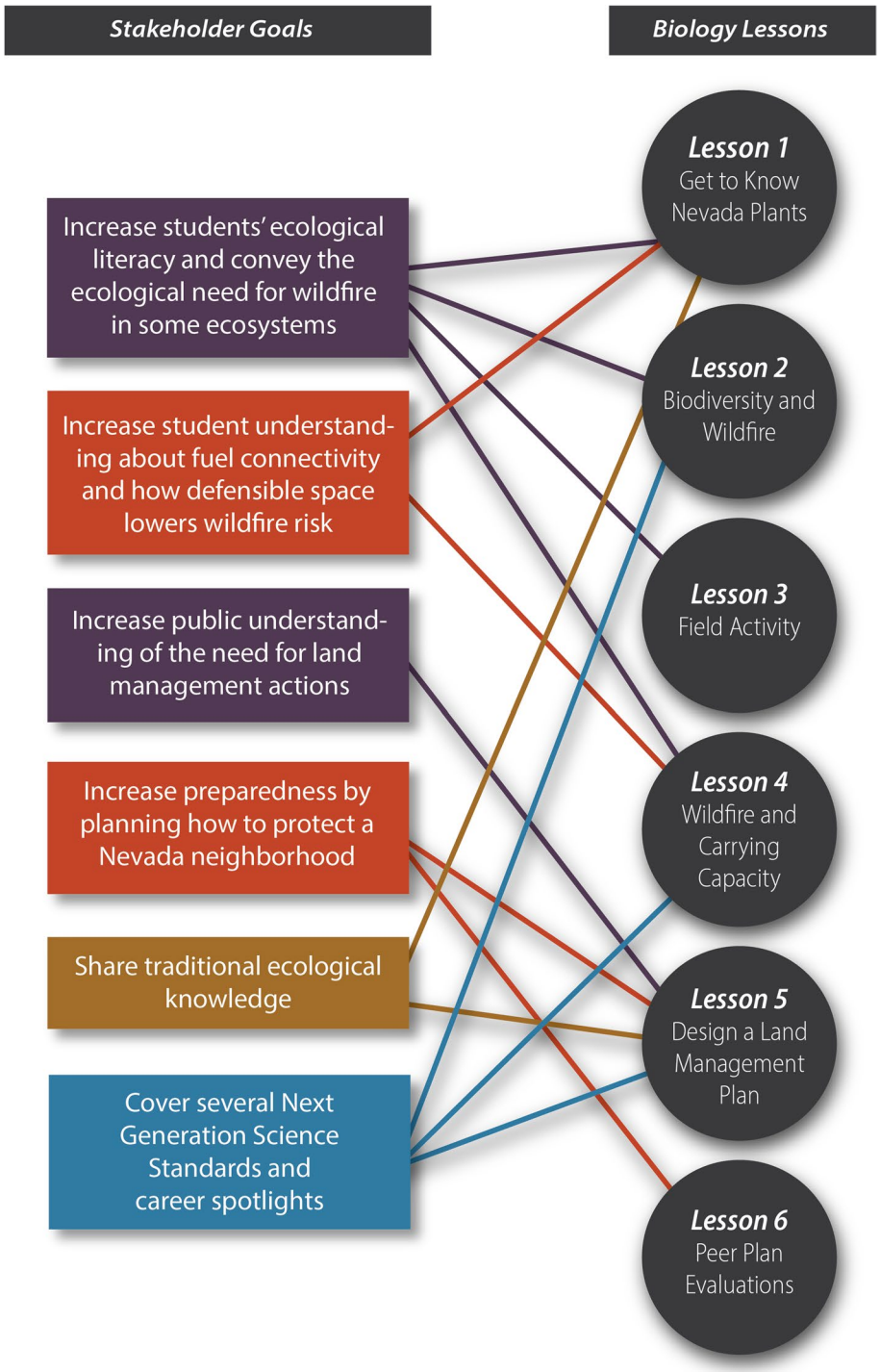

Fig. 3 The biology unit is divided into six lessons that each incorporates many different knowledge forms. The different colored boxes depict type of knowledge (purple = technical, red = management, brown = cultural, blue = institutional)

to respond to the statement "I can do things to help my home and community better survive a wildfire," students moved from 29 to 43% "Strongly Agree." When asked one thing students learned from these lessons that they did not know before, students shared the following:

> *"That wildfires can also increase [plant] populations while decreasing others because it takes away compe-*

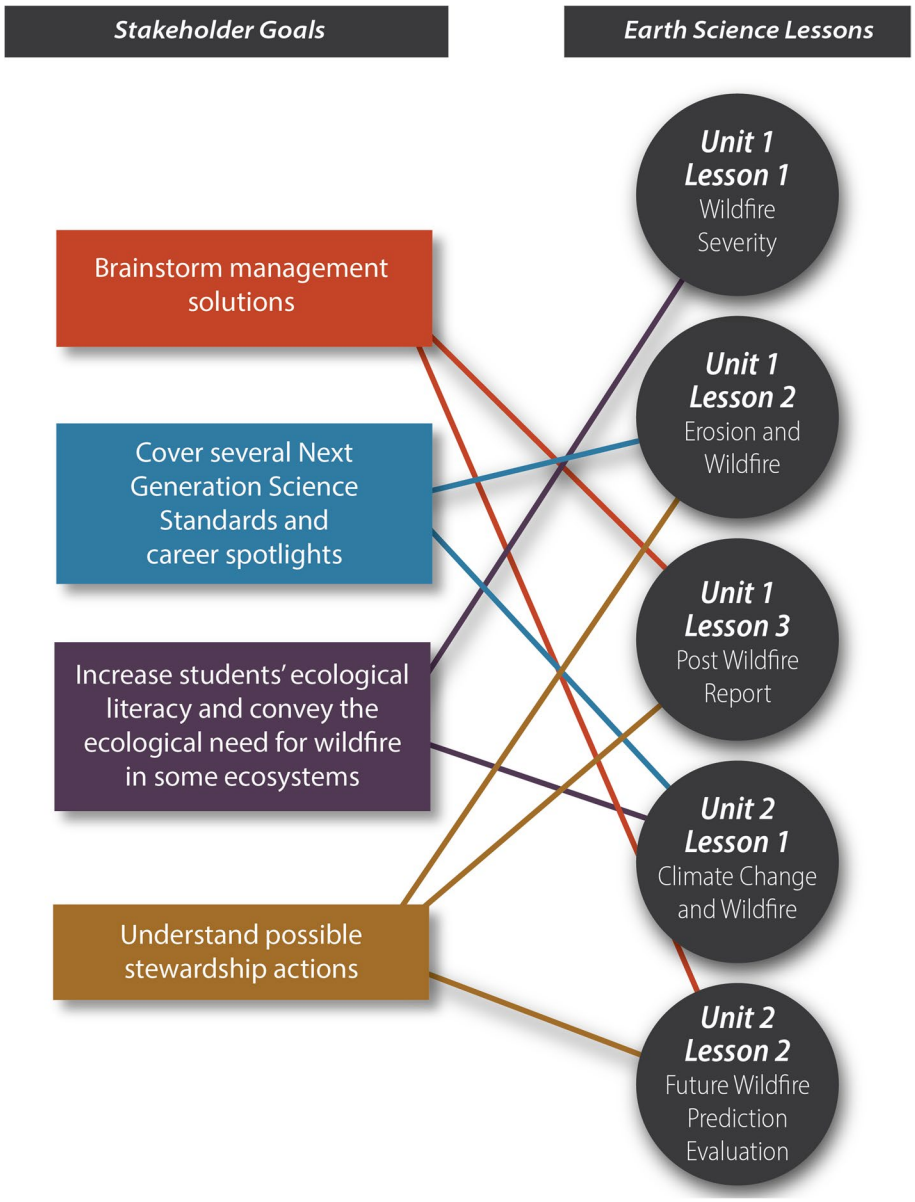

Fig. 4 The earth science unit is divided into six lessons that each incorporates many different knowledge forms. The different colored boxes depict type of knowledge (purple = technical, red = management, brown = cultural, blue = institutional)

tition and allows for more resources."

"One thing I learned about wildfire that I did not know before these lessons is that [a] smaller fire can be burned in order to remove the fuel for larger more dangerous and destructive fires."

"I had no idea that there were different types of firefighters. Learning about the wildland firefighters was very interesting."

Discussion

We worked with educators, fire and land managers, scientists, and tribal organizations to create a high school wildfire science curriculum to meet student needs in Nevada. The curriculum development process was unique in that we conducted an extensive and diverse stakeholder engagement process prior to developing the lessons. We then worked directly with teachers to co-produce content that resonated with their teaching context and required standards. In so doing, we developed a series of implementable curriculum units that fit into existing teaching constraints and are accessible to students' current learning environment.

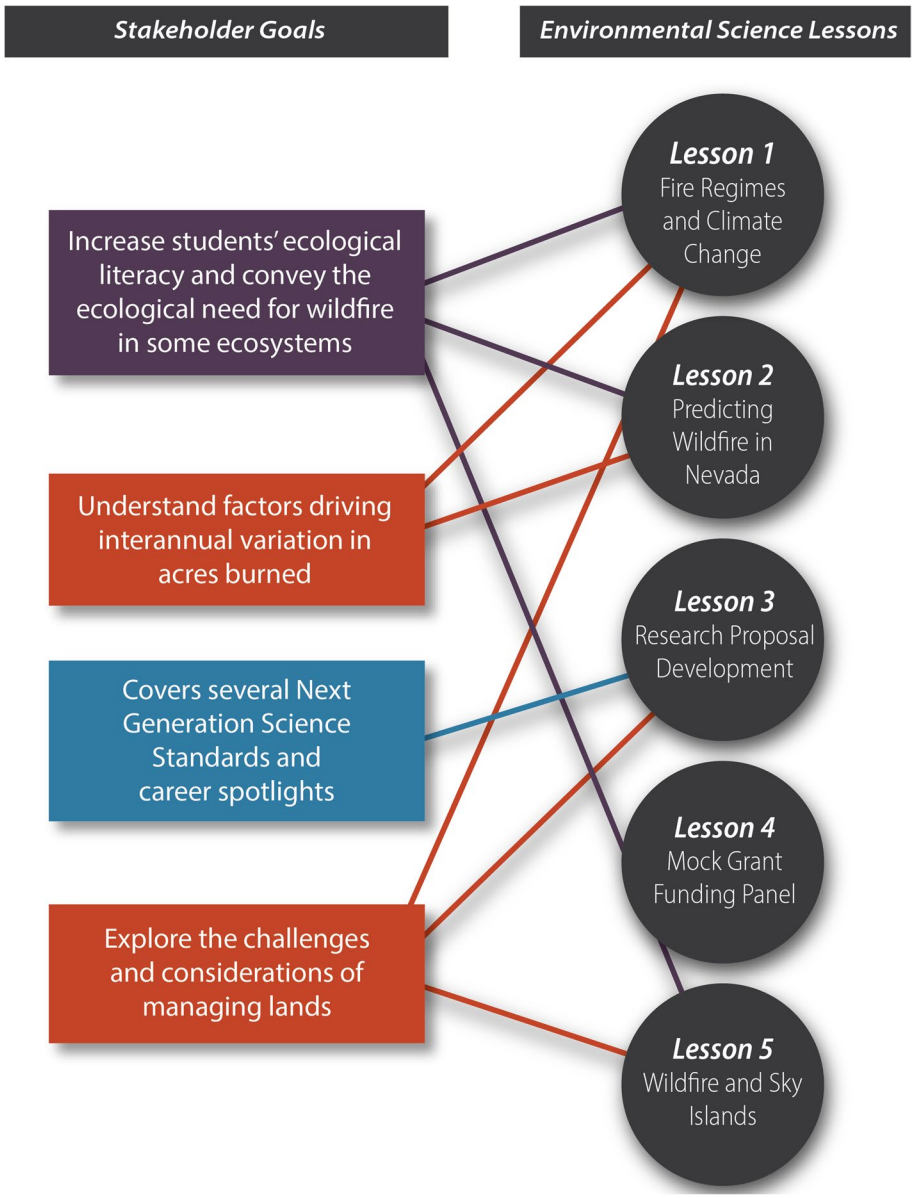

Fig. 5 The environmental science unit is divided into six lessons that each incorporates many different knowledge forms. The different colored boxes depict type of knowledge (purple = technical, red = management, blue = institutional)

Incorporating multiple knowledge forms into the curriculum proved challenging but rewarding. The scoping phase resulted in a large set of topics for inclusion in the curriculum. A primary challenge during the co-development phase was to then develop accessible methods to teach the diverse and technical goals that were identified, which included many topics that require a solid background of Nevada ecology. This process required at least five iterations of the biology unit; we often overestimated students' prior ecological literacy and needed to revise the lessons to better accommodate the post-pandemic learning environment. The result was robust lessons that included many different stakeholder priorities and values, while still meeting the needs of students and teachers.

We learned that Nevada students' exposure to fire ecology and ecological science prior to participating in these units is low. Any concept of wildfires comes almost exclusively from prevention messaging, such as Smokey Bear. Most students did not understand the nuances of fire and that there can be a need for wildfire in some areas. Students also did not have formal

education about wildfire preparedness. The dominant message they have received is to prevent wildfires from happening, rather than preparing for wildfires in a fire-prone environment.

This curriculum is the beginning of a larger emphasis on wildfire education in K-12 schools in Nevada. Creating and launching this curriculum spurred the development of a fire science career and technical track at a high school in Reno. The goal of this five-semester program is to prepare students for careers in municipal and wildland firefighting. We are working to (1) match existing entry-level firefighter training courses with the required Nevada Department of Education standards, (2) revise these courses to match the needs of high school students, and (3) provide training to land management agency instructors on how to teach high school students. This technical education program provides a more tangible way to create pathways to careers in fire, because students will graduate with professional certifications and are immediately employable by fire agencies.

We assert that this curriculum and other wildfire education programs in our region can increase our overall capacity for living with wildfire. As more students become knowledgeable about wildfire science, they gain a better understanding of the ecosystems in which they live and how they can be prepared for natural phenomena that frequently occur in their region. Wildfire is a complex socioecological issue that takes multiple approaches to find solutions. We need an educated population and a trained workforce to help tackle this problem. A new generation may have the fresh ideas that we need to learn how to navigate an uncertain future with more wildfire.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42408-024-00296-6.

Additional file 1: Appendices A, B, and C.

Acknowledgements
We acknowledge the many individuals that helped create this curriculum, including teachers and students that have participated in the curriculum. We would like to thank BLM staff for their support and help.

Authors' contributions
CR led the project, developed curriculum, and wrote manuscript. SE developed curriculum and wrote manuscript. MK developed figures and wrote manuscript.

Funding
This project was funded by the Federal Emergency Management Agency Fire Prevention and Safety Grant (Award # EMW-2019-FP-01112) and the Bureau of Land Management Fuels Management and Community Fire Assistance Program Activities Program (Award # L22AC00028-00).

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. The curriculum is available online at https://www.livingwithfire.com/resources/wildfire-science-curriculum/.

Declarations

Ethics approval and consent to participate
This study was approved by the University of Nevada, Reno Institutional Review Board (IRB #1891931–1 and 1994052–1).

Consent for publication
Not applicable.

Competing interests
The authors declare they have no competing interests.

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Received: 18 September 2023 Accepted: 29 June 2024
Published online: 25 July 2024

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