Canadian Journal of
Forest Research

OPEN ACCESS | Perspective

Challenges in teaching silviculture in Canada: the path forward

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Abstract

In times of unprecedented global change, forest management education, especially in silviculture, must evolve to prepare future forest managers with relevant skills and a comprehensive view of adaptive silviculture. As a data-driven science, silviculture must now integrate multidisciplinary technical and professional expertise to shape the forests of tomorrow—by planning and assessing treatment impacts while also meeting socioeconomic needs. As a result, silviculture education, particularly in undergraduate programs, needs to advance to meet these future challenges to ensure students have the essential tools and analytical skills required to undertake holistic, field-based silviculture practice. To support this advancement, we propose a vision for silviculture education that emphasizes fundamental knowledge (e.g., forest ecology, mensuration, governance), while also adapting to evolving concepts driven by socioeconomic factors, new silvicultural systems, a focus on ecosystem services, and the availability of new geospatial technologies. This new vision calls for strong leadership in experiential education to foster active learning through innovative tools, work-integrated experiences, and interdisciplinary collaboration. Such a curriculum will equip students with the skills required to integrate knowledge and adapt holistically, preparing them to meet the evolving demands of modern silviculture.

Key words: experiential learning, traditional ecological knowledge, forest management, forest education, pedagogy

1. Introduction

In times of unprecedented global change, shifts in climate, land-use practices, and biodiversity are causing the world's forests to experience considerable transformation. Not only does this drive a need for change in the way we implement sustainable forest management, but also the pedagogical approach and practical training required to teach the next generation of forest managers. Within forest management, silviculture has traditionally been thought of as the art and science of managing individual forest stands, specifically of growing and tending to forest crops to ensure a sustainable wood supply (Nyland 2016). The turn of the 21st century has seen silviculture evolve toward multifunctional objectives related to sustainability in a broader perspective (Pretzsch 2009). It remains a data-driven science, with the use of new technology and methods now providing far more data than before to measure the impact and the efficiency of silvicultural treatments in meeting socioeconomic demands and sustainability requirements (Achim et al. 2022). However, as we update our definition of silviculture (Puettmann et al. 2025) to the new realities of global change, undergraduate courses need to incorporate these concepts on top of the fundamentals of silvicultural teachings. Without these, the next generation of silviculturists risk missing the tools, analytical concepts, and holistic world-view, required to apply a comprehensive field-based approach to silviculture.

Here we argue that to respond to ongoing challenges, silvicultural education must ensure strong bridges between the fundamentals of silviculture competencies to the suite of current and future forest and societal needs—recognising the importance of critical concepts such as climate, socioeconomic realities, new technologies, and integration of risk management and uncertainty. We contend that to achieve this, teaching requires a more holistic approach to silviculture, highlighting the need for nimble, dynamic, and adaptive techniques. In practice, this leads to the teaching and implementation of treatments that actively aim to accommodate and/or facilitate change with the goal of maintaining forest health and resilience. Teaching of adaptive silviculture should also recognise the changing socioeconomic drivers, global demands for timber, and a more diverse range of goods and services provided by our forests. Lastly, silvicultural teaching must emphasize system complexity (Messier et al. 2013) including risk management and uncertainty in both future environmental conditions and decision-making built upon relationship building and collaboration.

As with many complex disciplines, challenges may arise in advancing a new approach to teaching silviculture, namely, (1) reduced enrollment in many Canadian forestry programs, potentially due to negative social perceptions of large-scale industrial practices such as visible clear cuts and removal of old growth timber (Bliss 2000), (2) uncertainty of concrete actions to implement future silviculture treatments, (3) bridging foundational, professional, and silviculture competencies, which can limit innovation within and between undergraduate courses, (4) difficulties incorporating hands-on silviculture training skills due to financial and logistical challenges such as health and safety, diversity, equity and inclusion, and different cognitive abilities, and (5) strict curriculum requirements driven by overarching accreditation competencies whereby universities are reluctant to make substantial curriculum changes. Without overcoming such challenges, future silviculturists risk entering the workforce ill-equipped to implement adaptive silviculture in a constantly changing environment (Nordin and Comeau 2003).

Conventional 4-year undergraduate calendars are currently aimed at bridging competencies across all learning objectives of both professional and practical courses. However, guiding principles are required to advance interdisciplinary collaborations without creating multiple pockets of expertise that become siloed into individual fields of studies. In this paper, we aim to conceptualize current views of Canadian silviculture in the 21st century and the need to adapt current and future learning objectives and competencies to educate the next generation of silviculturists. We review the current challenges to teaching silviculture that risk limiting the tools in a silviculturists' toolbox, as well as maintaining the foundations of silviculture that remain essential over time. Using this foundation, we review critical concepts for future silviculturists to iteratively analyze and apply in both the classroom and the field in the face of global change. We emphasize the importance of teaching risk, complexity, and uncertainty as a way to assess adaptive silvicultural practices. Additionally, we provide recommendations to enhance existing tools and integrate new course material through experiential education. We propose that once these changes in teachings have been established, future silviculturists will have a better appreciation for a holistic field-based application of silviculture. With this new vision, future silviculturists will be able to create and apply innovative tools and approaches that will sustain the health and social–ecological resilience (Nikinmaa et al. 2020) of Canadian forests.

2. Challenges in teaching silviculture

The teaching of silvicultural principles in undergraduate education faces ongoing challenges, as summarized in Table 1. Here we review these challenges and how they impact the teachings of silviculture. To respond to these challenges, we outline guiding practices, which we expand upon in subsequent sections (Table 1). We also propose solutions to these challenges and these are synthesized in Fig. 1.

2.1. Low enrollment and social acceptance

After a peak in the 1970s, enrollment in the majority of forestry programs in North America declined in the 1980s and has not recovered (Miller and Lewis 1999; Nyland 2008; Sharik and Frisk 2011; Sharik et al. 2015). In response to greater public awareness of ecological issues, curricula in forestry programs expanded to include a broader perspective of environmental sciences, natural resource management, social science, and policy. Nevertheless, this modernization of forestry programs has not resulted in a substantial increase in undergraduate enrollment (Sharik et al. 2015), which some have attributed to the declining reputation of forestry as an industry, including shifts in social importance of forestry, lack of trust from the general public in forest management at all levels of government and industry, and concerns regarding transparency, monitoring, and governance of forest decision-making (Bliss 2000; Nyland 2008).

As a branch of forestry, the discipline of silviculture has many of these same challenges. However, since the 1990s silviculture has addressed many of these societal concerns by integrating a number of ecosystem-based management ideals (Beese et al. 2019), which have historically demonstrated high levels of public support (Findlater et al. 2020) and have been implemented on a much broader scale than before (Province of Québec 2013; Province of Alberta 2016; Province of British Columbia 2018). In doing so, there has been a growing recognition by silviculturists (and forest managers more broadly) of the need for interdisciplinary teams to develop and implement innovative forestry solutions that respond not only to requirements for timber, but also meet ecological and sociological goals that in turn are met with support and trust from the public (Nelson et al. 2017).

2.2. Relying on single disciplinary teaching teams

Adaptive silviculture primarily focuses on the development of individual stands, though it also considers many landscape-level objectives that include a broader array of forest ecosystem goods and services. As such, the field of silviculture has grown to become more interdisciplinary whereby we are now requiring silviculturists to have understandings of (1) technologies such as geographic information systems (GISs) and remote sensing, (2) big data, computer modeling, and simulation, (3) forest ecology and interactions with surrounding disciplines, (4) social dynamics and policy implementation, and (5) written and oral communication skills. Such a wide range of skills cannot fall to a sole instructor in a single course and instead require a series of adjacent courses where these concepts can be taught, assessed, and applied practically (Jain et al. 2017). In the absence of this broad multidisciplinary knowledge base, silviculturists entering the job market may be naïve in some areas with employers

Table 1. Challenges of teaching silvicultural principles in undergraduate education.

Challenge	Description	Guiding practices and further discussion
2.1 Low enrollment and poor social perception of forestry	• Enrollment in forestry programs has been declining since the 1970s, potentially due to the declining reputation of forestry and more variety in career choices outside of forest industry • More regulated and ecosystem-based management have historically shown higher levels of public support • Interdisciplinary teams are required to effectively respond to economical, ecological, sociological, and philosophical variables that are now essential components of silviculture	Section 5.3: Exposing the student body to real-world scenarios, socioeconomic drivers, partnerships, collaborations, and the forestry community provides a two-way street for the general population to see different perspectives of forestry in practice to attract more students to undergraduate forestry programs
2.2 Increasing multidisciplinary teaching teams	• Silvicultural training requires a diverse set of skills across multiple fields, which cannot be taught by a single instructor • Instead, instruction should be shared across multidisciplinary teaching teams • Multidisciplinary teaching can be organizationally challenging, particularly ensuring skills are taught at the same level consistently across years and programs	Section 5.1: Interdisciplinary tools, technologies, and teachings can be used to enhance learning Section 5.2: Using these skills through interdisciplinary programs such as co-op programs, field courses, and community forests promote experiential learning for the students and reduces pressure for a single instructor
2.3 Difficulties implementing experiential learning	• Experiential learning brings financial and logistical challenges with a greater focus on health and safety, and the cost of maintaining a safe environment for all students • Forestry schools aim to diversify their student body with the challenge of addressing equity and inclusion, which require greater training and resources	Section 5.1: Innovative technologies can help overcome barriers of physical excursions to promote equity and inclusion Section 5.2: Partnerships through co-op programs and community forests promote experiential learning at a reduced cost to the universities and students
2.4 Quantifying uncertainty	• Challenges in addressing the complexity of decisions around risk and adaptive management increase with the variability in the forest environment and volatility of timber markets	Section 4.5: Reiterates the importance of forest complexity and teaches students how to address uncertainty and risk for real-world applications Section 5.1: Students learn to incorporate risk and uncertainty with field data and silviculture tools via interdisciplinary teaching methods Section 5.3: Students are exposed to real-world scenarios through partnerships and collaborations to see how quantifying uncertainty is done in practice
2.5 Barriers of accreditations and changes in curriculum	• Forestry accredited universities must follow rigid curriculums to meet several specific learning objectives • Substantial changes require substantial alterations to courses or programs that would need to be re-assessed for accreditation approval • Universities are reluctant to make changes because there is a short-term risk of defining visionary learning objectives that may not reflect current needs of industry	Section 5.0: Pioneering programs in Canada and abroad that have overcome such obstacles in the past should be reviewed for potential implementation across Canada

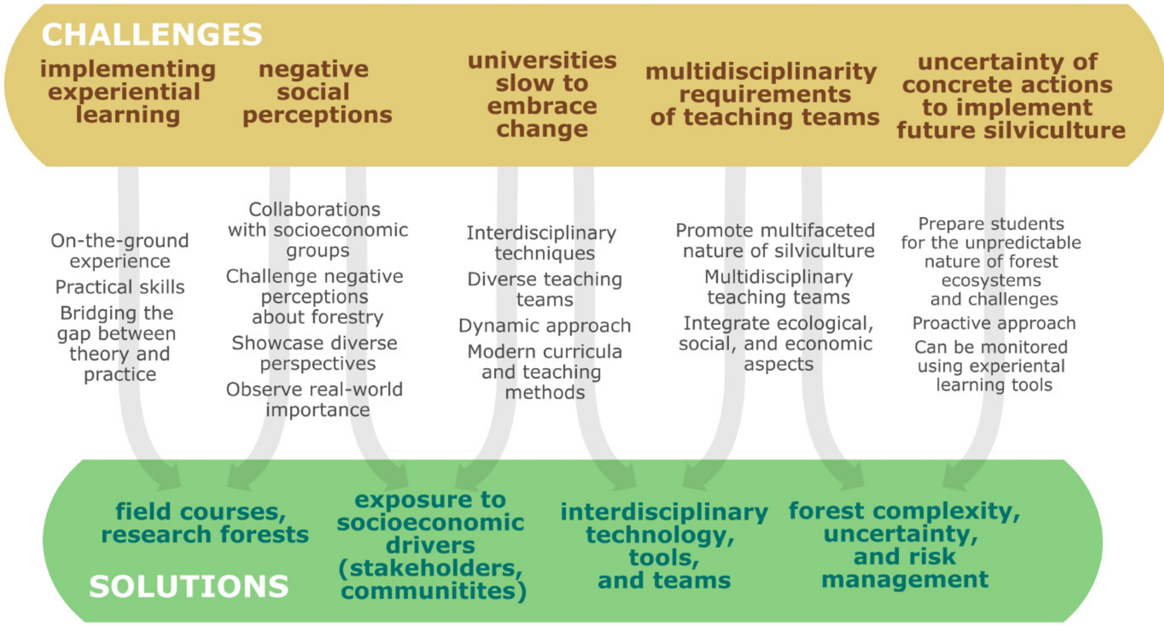
Note: For each challenge we have summarized our suggested guiding practices and the section in which they are discussed in greater detail.

recognizing gaps between their technical and professional skills (Kelly and Brown 2019). Such multidisciplinary teaching can be organizationally challenging, particularly in ensuring that skills are taught at the same level and consistency across year levels and programs (DeRose et al. 2023).

2.3. Difficulties implementing experiential education

Teaching silviculture—as well as other forestry-related courses—relies heavily on an experiential education, whereby programs devote considerable resources toward hands-on practical training to build both technical skills and understanding of forest ecosystem functioning (Leslie and Wilson 2009). Experiential learning is simply defined as using different methods to engage with students to offer a direct, hands-on experience along with a focused reflection (Kolb 2014; Schenck and Cruickshank 2015) to promote greater learning, skill development, value clarification, and the capacity to contribute to a community. Common examples include field courses, field trips, and exposure to research forests and outdoor field labs. To truly provide a context for experiential learning, these activities must be structured to incorporate interactions and tasks that actively engage learners, encouraging them to practice active reflection and critical thinking. Unfortunately, this is accompanied

Fig. 1. Potential solutions to address current challenges of teaching adaptive silvicultural principles in undergraduate education.



with greater financial and logistical challenges for effective teaching (Leslie and Wilson 2009; Culbert 2021). An important focus on health and safety, along with the cost of ensuring a safe learning environment—often in remote locations—is increasing and requires additional teaching resources to ensure an effective and safe learning environment (Yarincik et al. 2023). As a result, the associated financial cost of these programs is increasing and can become prohibitive to provide these experiences.

At the same time, forestry programs are aiming to diversify their student body in terms of gender, as well as ethnic and academic backgrounds (i.e., field of expertise and practical experience). It is known that greater diversity in research teams promotes better quality science (AlShebli et al. 2018); however, there remain discrepancies in the benefits of experiential education to different racial and ethnic groups, as well as between first- and second-generation students (Eddy and Hogan 2014). It has been shown that incorporating field components into traditional classrooms not only increases student performance (Easton and Gilburm 2012) but disproportionately so for females, racial groups, and first-generation students (Beltran et al. 2020; Odom et al. 2021). These field components, however, have also been deemed overall less safe for marginalized identities (Rudzki et al. 2022). Addressing this need to implement experiential education to make programs for equitable, accessible, and safe requires further training and resources for instructors and university staff. Though this necessitates additional efforts from universities and faculties, it also presents a valuable opportunity for silvicultural faculty to develop innovative teaching methods and tools to overcome these barriers.

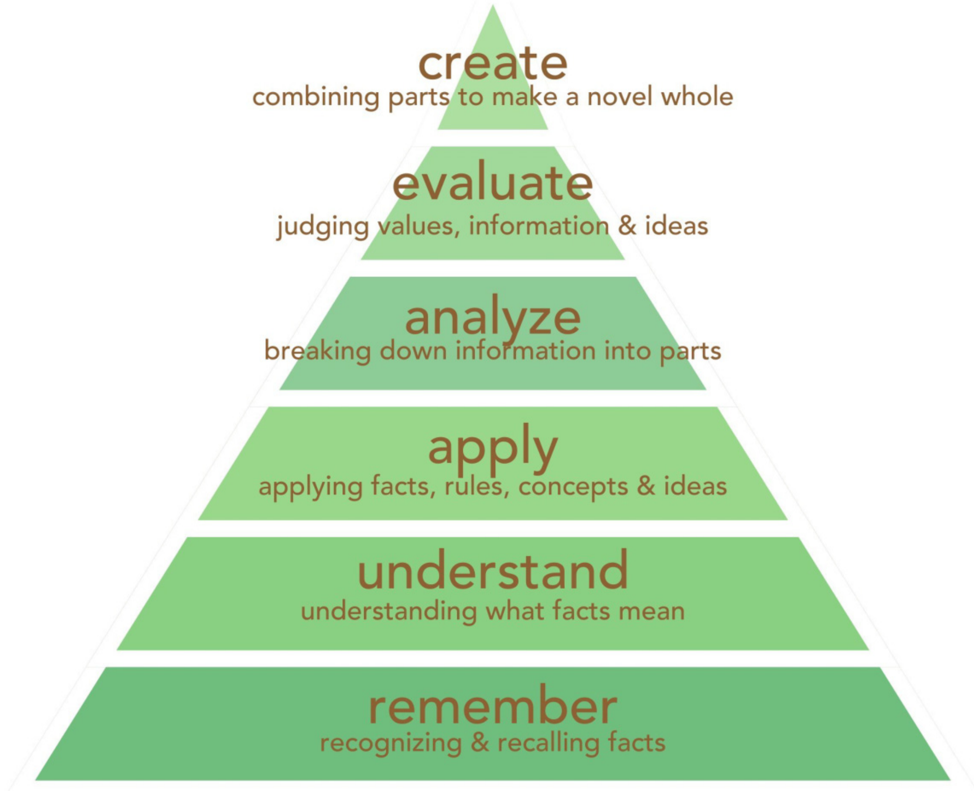
2.4. Quantifying uncertainty

Variability in climate change projections and disturbance frequency across the landscape enhances the complexity of forest resource utilization and uncertainty (Wallin and Brukas 2024). This uncertainty requires silviculturists to undertake complex decision-making processes, which consider risk and adaptive management strategies (D'Amato et al. 2023). When making decisions for future management, understanding risks is an important concept for undergraduate students to develop early on in their program. This has always been an issue on how to teach both the science and the art of silviculture. However, the number and complexity of decisions related to risk and adaptive management are increasing with the variability in the forest environment and volatility of timber and other ecosystems goods and services markets (Lochhead et al. 2016). This increased need for quantification of risk presents challenges in both how we teach, and then demonstrate the implications of various silvicultural systems in forest management today.

2.5. Barriers of accreditations to changes in curriculum

Bringing change in how we teach silviculture in the 21st century remains challenging due to rigid academic curriculum, particularly in accredited forestry programs where many specific learning objectives must be met (such as through the Canadian Forestry Accreditation Board (CFAB)) throughout a 4-year program. Any substantial changes to learning outcomes or course material can have major impact on related courses and programs, as well as the ability of students to move between programs (such as from a training technical college into a 4-year university degree or from one faculty to another). Instead, incorporating new courses could require considerable changes to programs that have already been accredited by the CFAB and would need to be reassessed at regular intervals to ultimately be approved and ratified (Innes 2005). As a result, universities may be reluctant to make substantial changes to the silviculture curricu-

Fig. 2. Bloom's taxonomy representing the hierarchical order of cognitive skills. Adapted from Bloom's taxonomy by Anderson and Krathwohl (2001).



lum in the short term, viewing changes to the requirements by accreditors as a potential risk to learning objectives and experiential opportunities that may not necessarily reflect the immediate and near-term needs of the forest industry (Tagg 2012).

3. The fundamentals of silviculture

Silviculture is a critical component of forestry whereby many shared concepts form a foundational understanding upon which develops a more advanced curriculum. Foundational courses in early years of silvicultural programs often employ lower levels of the cognitive domain (Fig. 2), with learning objectives centered around remembering and understanding facts, concepts, and ideas and applying them to new situations, as outlined in Bloom's taxonomy (Bloom 1956).

In this section, we outline fundamental concepts and overarching learning objectives for foundational forestry courses on which more advanced silviculture material will continue to be built. Since it is important to incorporate multiple levels of cognitive abilities in each class, we discuss future considerations and competencies that will become increasingly important as we consider adaptive silviculture in the context of global change and to challenge students' cognitive abilities. We recognize that each topic is a field in its own right, each with a vibrant discussion around effective pedagogical principles, and is not fully represented in the following text. This section is summarized in Table S1 of the supplementary material.

3.1. Forest ecology

Forest ecology is the study of ecological systems and the mutual interactions between organisms and their environment and is often thought of as the precursor to silviculture (Olivier and Larson 1996; Ashton and Kelty 2018). In a silvicultural context, the multiple disciplines within an ecological curriculum provides students with understandings around core ecological principles of interactions between plants and forest ecosystems functioning. This allows students to understand how underlying ecological principles may be altered by variations in environmental conditions. Over time, forest ecology courses remain an essential component of future concepts learned in adaptive forest management strategies (such as sustainability, species responses in novel environments, and assisted migration) from both ecological and ethical perspectives.

3.2. Silvics and silvicultural systems

In silvics courses, students learn tree species' life history and characteristics both within their stand and their influence on and by the environment (McGill et al. 2006). In a constantly changing environment, silviculturists learn to analyze potential changes in resource demand, both through ontogenetic stages with frequent discordance between regeneration and growth niches (Schupp 1995) and with predicted climatic stresses, disturbances, pests, and diseases (Boulanger et al. 2017). In fundamental silviculture courses, this is considered in the teaching of silvicultural systems, which relate sequences of silvicultural interventions to stand dynamics, regeneration, and establishment, in response to both intra- and interspecific variation and environmental plasticity within an ecosystem (Messier et al. 2010; Westerband et al. 2021). In upcoming years with greater intensity and uncertainty of global change, these interactions—including those with tree species functional traits (Aubin et al. 2016)—will become more important for student learning, particularly in understanding tree silvics as complex systems in a state of flux rather than constant equilibrium.

3.3. Forest mensuration and biometrics

Forest mensuration and biometrics are the basis of any forestry curriculum, providing the tools and methods to conduct quantitative assessments of tree and stand attributes in the forest and their development over time (Kangas and Maltamo 2006; Kershaw et al. 2016). Courses in forest measurements cover individual tree and stand-level measurements as well as principles of sampling design (Kershaw et al. 2016; Burkhart et al. 2018), which require understanding of basic statistics and sampling theory. Subsequently, forest modeling courses typically cover growth and yield model development and more advanced statistical analysis (Weiskittel et al. 2011; Burkhart and Tomé 2012; Mehtätalo and Lappi 2020), which are usually taught at the graduate level. However, to fully understand these more advanced analyses, introductions to statistical theory should be incorporated much earlier on (Dennis 2004). Growth and yield models are essential to silvicultural decisions as they provide insights into future stand conditions and must incorporate climate sensitivity to support decision-making under climate change (Metsaranta et al. 2024). These disciplines require technical abilities and advanced statistical analysis, raising the need for silviculture students to have strong statistics skills, which in turn require a solid foundation in mathematics, specifically in calculus and linear algebra. As more key tools and data are brought for mensuration and biometric consideration, such as through advances in remote sensing technology, instructors should also emphasize the importance of sampling theory to give students the ability to adapt statistical approaches and generate accurate and meaningful information (Temesgen et al. 2007). This is crucial, as this information will form the basis for decision-making regarding which silvicultural treatments to apply to achieve a variety of production objectives.

3.4. Mapping and spatial data

Geomatics principles are underpinned in geodesy, map projections, and cartography; essential digital tools that help silviculturists generate spatially explicit information on trees and stand attributes. Over the last few decades, the availability of advanced geospatial datasets and increased computational power has placed an emphasis on understanding geospatial principles to inform landscape-level decisions to achieve multiple goals and for long-term monitoring. For this reason, geomatics is an increasingly important science for silviculturists to comprehend and utilize to its full potential (e.g., Fassnacht et al. 2024; Goodbody et al. 2024). Future instructors must acknowledge the importance of computer-science material and work on incorporating it into their teachings to bridge the gap between new technology and silvicultural prescriptions.

3.5. Climate science

Climate science has been traditionally covered in subjects such as atmospheric physics, meteorology, geography, and biology but is now critical for silviculturists to understand the impact of future climate change on forest structure and composition (Eichorn 2011). A key to the application of adaptive silviculture is also that students learn how to access and interpret climate projections for a range of plausible futures (Wotherspoon et al. 2024). Additionally, this means bridging the gap between this knowledge and the connection to the silvics of species and what conditions are optimal for future growth. As silviculture becomes more dynamic, students should also understand the ways in which climate change is complex and exists within broad societal contexts including nature and culture, global perspectives, contextual and subjective knowing, reflection of human needs, and open dialogue learning (Cook 2019).

3.6. Forest operations

The success of silvicultural planning is ultimately dependent on the efficiency and sustainable practice of forest operations (Uusitalo and Pearson 2010). Courses in forest operations help future silviculturists understand the complexity of the field including operational considerations, logistics, constraints, and safety requirements for varying landscapes, terrains, and tree species. This also includes the productivity of the forest, logistical planning, machine efficiency, and supply chain economics based on mathematically informed decisions (Ackerman et al. 2014). As silvicultural treatments become more complex over spatial and temporal scales to achieve multiple stand objectives, harvesting plans must not only become more robust while being competitively efficient, but also maintain ecological integrity and social trust (Marchi et al. 2018; Schweier et al. 2019). To do so, courses should continue to teach optimization tools and techniques for silviculturists that will ultimately be used by operation managers.

3.7. Wood processing

Though it may target the provision of other ecosystem services (Achim et al. 2022), the production of wood as a renewable material is often central to silvicultural action. Even when not the main purpose, wood production is key to providing the revenues that offset the cost of operations (Barnett and Jeronimidis 2003). Wood processing courses teach the basics of wood processing technologies (Walker 2006), wood anatomy, and material properties (Wilson and White 1986), and how these are impacted by various silvicultural decisions (Barrette et al. 2023). As innovation in wood primary and secondary processing advances (Walker 2006), courses should continue to emphasize how the economics of the wood value chain are evolving and how they are linked to the

Can. J. For. Res. 55: 1–19 (2025) | dx.doi.org/10.1139/cjfr-2025-0081

implementation of silvicultural treatments to promote forest vigour, resilience, and growth. Such courses are also essential prerequisites for courses that specialize in later stages of the forest value chain, such as timber engineering (the design, analysis, and construction of timber structures).

3.8. Forest economics, governance, and values

Economics has previously been the cornerstone of forestry to guide and constrain the decision-making capacity of Canadian landscapes. In Canada, ~90% of forested land is publicly owned and managed by provincial and territorial governments, emphasizing the importance of silviculturists' to respond to the broader needs and expectations of society (Vonhof 2010). This includes silvicultural treatments aimed at promotion ecosystem health and productivity (e.g., reforestation actions, density management, fuel reduction, and beyond), which have been traditionally mainly driven by cost-benefit analysis. While the importance of managing for multiple and diverse values is crucial, this view often obscures the historical, ongoing, and widespread dispossession of land by settler-colonial governments through racist laws and practices. In many areas of Canada, land that is characterized as Crown/public land, is in fact, unceded Indigenous territory, such as is the case for the vast majority of forest lands in British Columbia. Now as adaptive management aims to address multiple ecosystem services, risk assessment (e.g., Brèteau-Amores et al. 2022, 2023) as well as uncertainty to identify trade-offs and decision-making (Raunikar and Buongiorno 2007), past harms in forestry decision-making should be addressed moving forward (e.g., through the Truth and Reconciliation Commission Calls to Action). Through courses in various realms of the social sciences, including forest governance, students should gain a solid foundation of the ongoing tensions, competing, and evolving systems of governance related to forests that they may one day be working in. Students should also understand the diverse values, worldviews, and epistemologies that underpin different objectives for forest governance. As adaptive silviculture works toward reconciliation, collaboration, and a linked human-environment approach (Moran 2011), instructors must ensure students understand the complex relationship between meeting the needs and the ecological implications of the forest sector but also how to measure and interpret the adherence of various publics to silvicultural strategies that are implemented. Instructors must ensure students are prepared with the awareness and skills to engage with partners and Indigenous community members without doing harm.

4. Evolving concepts in silviculture

As undergraduate students successfully understand and recall these foundations of silviculture, they then advance to more specific course material whereby—in accordance with Bloom's taxonomy—they work to analyze critical concepts, evaluate larger scale and more complex scenarios, and form novel ideas (Bloom 1956). It is essential for future silviculturists to be able to include a broad suite of complex and interconnected issues given the pace at which the environment is transforming due to global change.

In the following section, we review emerging critical concepts and skills that have recently been—and will continue to be—required by students in advanced silvicultural learning. These concepts, that may also address some of the challenges of silviculture education (Fig. 1), will need to be continually re-applied and re-analyzed in response to global change and the context of this silviculture education framework.

4.1. Adapting to new silvicultural systems and scales

Historically, and by definition, silviculture focuses on decisions made at the stand scale, i.e., contiguous groups of trees with enough homogeneity to form a distinguishable unit (adapted from O'Hara and Nagel 2013). However, given the changes in the frequency, severity, and extent of climate-driven changes in disturbance (Seidl et al. 2017) silviculture should remain in tune with changes in scale other than at the stand level. This can include promoting a range of silvicultural decision-making from the individual tree level (such as precision forestry e.g., Keefe et al. 2022; Rautio et al. 2023) and within-stand variability including connectivity and β-diversity (Aquilué et al. 2020; Müller et al. 2021). At the landscape level, different types of silvicultural systems should be studied and how trees react and interact at various spatial and temporal scales (Searle et al. 2021). Otherwise, well-meaning silviculturists may make decisions regarding stand composition and structure that are logical at the stand scale, but lead to deleterious effects at the landscape scale (such as further homogenizing the forest landscape) and in so doing increase its vulnerability to global change.

4.2. Forest ecosystem goods and services

Silviculture is a discipline that has traditionally focused on the extraction of wood resources for commercial purposes. Silviculturists therefore play a critical role in safeguarding and enhancing future forests for timber values, but also in ensuring the ecological integrity and functionality of these forest ecosystems for other forest ecosystem goods and services in the future. However, current and future students learning about the role of silviculture require a more contemporary understanding that recognizes the multifaceted ecological, social, and economic values that forests provide. This creates a shift in silvicultural perspectives from considering wood extraction as the main objective, to understanding that silviculture can facilitate management of a diverse array of ecological goods and services. This can include not only enhancing timber value and stand health through silvicultural treatment (Thiffault and Pinno 2021) but also (1) biological conservation whereby forest structure and composition can be managed to contribute to the preservation of particular species or ecosystems (Pinno et al. 2021; Bartemucci et al. 2022), (2) regulating services including the use of vegetation to prevent sediment erosion, control of temperature and moisture through canopy shading, and filtering of runoff improving water-quality of downstream systems (Thiffault et al. 2023; Ring and Sikström 2024), (3) provisioning services to maintain fish and wildlife populations for hunting, fishing, trapping, and harvesting (Corkery 2024), (4) cultural management or conservation whereby tree species or forested stands have an important role in spirituality and are providing direct goods such as basketry and crafts and indirectly through intrinsic relationships (Greenlaw 2023; Boudreault et al. 2024), and (5) contributions to genetic, functional, and response diversity for their role in forest resilience to global changes (Mori et al. 2013), while also regulating climate, mitigating the risk of disturbance, particularly fire (Moreau et al. 2022), and influencing global carbon cycles and carbon dynamics (Ameray et al. 2021).

4.3. Geospatial technologies

Fundamental courses provide a basic understanding of how technology impacts key learning outcomes in silviculture (Table S1). However, a nuanced understanding of technology is necessary for a broader discourse on silvicultural management due to its transformative impact on forest management practices. Technological innovations have caused a paradigm shift in silviculture, offering a variety of tools and methodologies that are capable of enhancing the mensuration techniques, as well as the precision, efficiency, and sustainability of forestry operations (de Araujo Barbosa et al. 2015; White et al. 2016; Queinnec et al. 2022). This shift constitutes the adoption of data-driven silvicultural design, facilitated by technologies such as GIS and remote sensing, which provide a granular understanding of forest stands (Table 2). However, it still remains important for students to understand the advantages and limitations of different technologies, how they can be used, and when they are most appropriate for the given question (Rautio et al. 2023; Fassnacht et al. 2024).

When asked about career aspirations, students often express interest in utilizing high-end technology as a key goal (Kelly and Brown 2019). Systems such as Global Navigation Satellite Systems, the American Global Positioning System (GPS) and the European Galileo systems have become critical pieces of technology for silviculturists (Sonti 2015; Pandey et al. 2022) by supporting precise spatial position of silviculture prescriptions and should therefore be an integral part of silviculture courses (Unger et al. 2014, 2018). Utilizing innovative technologies can facilitate active learning in the classroom and the understanding of novel system components (Table 2). Throughout the education process, progressive learning approaches should incorporate research techniques that promote complex and realistic problem solving (Richards and Robak 2008). An extensive list of technologies can be utilized in the classroom—Table 2 provides some brief examples that can help meet higher level learning objectives while also bridging competencies with other skills.

4.4. Indigeneity and diverse perspectives

The incorporation of diverse perspectives and worldviews into silvicultural education is a pressing issue that requires critical attention from educators and curriculum developers in Canada and globally (Grande 2015). A current goal is the Indigenization of the curriculum to facilitate the integration of Indigenous perspectives, knowledge, histories, cultures, and language into the curriculum with the aim of achieving several key objectives.

The first goal is to create a more inclusive and equitable learning environment that reflects Indigenous understandings of forest and forest ecosystems, both in Canada and globally (MacEachren 2018; Sungusia et al. 2020). To achieve this, the silvicultural curriculum should be revised and rethought to better serve Indigenous students taking these courses (Battiste 2014), which will ultimately promote cross-cultural understanding among all students. The curriculum should reflect the identity and perceptions of Indigenous students in both fundamentals and more advanced silvicultural classes throughout the undergraduate program. It is important to recognize the strong ancestral links that many of these students have to their land (Whyte 2018), which was—in many cases—stolen and forcibly occupied through ongoing processes of systemic racism and settler colonialism in Canada. Indigenous students' worldviews around forests are likely to be markedly different from others in the classroom. Therefore, Traditional Ecological Knowledge, often handed down through generations, should sit alongside the western scientific knowledge that has traditionally been covered in applied ecology and silviculture (Jessen et al. 2022). This should also include acknowledging Indigenous histories and contributions to the management of our forest ecosystems today (Whyte 2018). Not only does this help make the curriculum more accessible to Indigenous students but also promotes the accuracy of the history, experiences, and contributions of Indigenous people, both past and present, to forested ecosystems. It is important to recognize the inextricable relationship between Indigenous identity and land, and that (re)connection to land is a critical aspect of reconciliation. The silvicultural curriculum should also reflect the new reality of recognizing Indigenous sovereignty on forest lands (Sabzalian 2019). Many countries worldwide are recognizing the land claims of Indigenous peoples to forests and transferring ownership, management, and conservation of these forested ecosystems to them. Academia and students studying silviculture should be aware of the complex history and reconciliation of forest ownership. It is probable that Indigenous communities will support students in developing additional skills to manage these forests for their respective nations.

The second goal is co-managing forests with Indigenous communities to develop silvicultural prescriptions that meet the needs of all forest users, including Indigenous communities, is critically important (Baynes et al. 2015; Pinkerton 2019; Fa et al. 2020). Students must learn to listen and collaborate with Indigenous elders, knowledge keepers, and community members to ensure that the silvicultural decisions made are appropriate and represent the desires of the community as a whole. This must also crucially acknowledge the substantial forestry knowledge possessed by Indigenous communities through their elders and knowledge keepers (Carson et al. 2018). It is becoming increasingly evident, particularly in the area of fire management, that Indigenous communities have developed their own management strategies to support their communities, preserve biodiversity within forests, and ensure community safety. For example, the practice of

Table 2. Examples of innovative technology, how they can be used to teach varying components of silviculture, and potential teaching tools to put them into practice.

Course learning objective	Possible technologies	Competencies and tools taught	Examples in the literature
Measure and analyze tree and stand attributes (i.e., height, diameter, and species) and use data to assess forest health and dynamics	• Unoccupied aerial vehicle remote sensing • Lidar • Virtual reality	• Collect and analyze data for stand inventory, remote monitoring, silviculture surveys, stand recovery, creation, roads, tree/stand health • Acquire, process, and manage remote sensing data for forest management applications • Integrate spatial data into silvicultural planning for effective decision-making • Address variability and uncertainty in information systems to improve reliability	White et al. (2016); Pandey et al. (2022); Queinnec et al. (2022); Riofrío et al. (2022); Morin-Bernard et al. (2023); Irwin et al. (2025); Tompalski et al. (2024)
Analyze and map landscape patterns with GIS and remote sensing tools, as well as create visuals to communicate findings and inform decisions	• Satellite remote sensing • Geographic information systems (GISs) • Interactive web mapping	• Aggregate and summarize data to effectively engage stakeholders in decision-making processes • Conduct stand delineation based on composition and disturbance, assess site suitability and develop landscape-level plans • Analyze and evaluate large datasets to create reports and inform policy implementation	Unger et al. (2014); National Forest Inventory (Beaudoin et al. 2017); operational forestry (Keefe et al. 2022); National Terrestrial Ecosystem Monitoring Service (White et al. 2017)
Plan reforestation with optimal species and planting arrangements, while balancing economic, ecological, and social goals	• Precision planting machinery • Data-driven site level mapping and selection	• Apply evidence-based approaches that align with ecological imperatives with socioeconomic expectations	Ramantswana et al. (2020)
Understand the principles and applications of growth models in forestry	• Climate-sensitive growth models • Growth simulation software	• Analyze growth simulations to assess the impacts of silvicultural treatments on stand development, forest productivity, and carbon storage • Assess uncertainty in growth model predictions to support management decisions	Dufour-Kowalski et al. (2012); Metsaranta et al. (2024)
Understand how climate projections utilize climate science and historical data, and their interactions with forests	• Spatially explicit climate projection data • Experimental silviculture climate trials	• Evaluate future climate scenarios as well as tree species that will be best suited • Use data to guide adaptive forest management practices and silvicultural treatments • Incorporate risk assessments related to future climate scenarios into forest planning and management	ClimateNA (Wang et al. 2016); Adaptive Silviculture for Climate Change (ASCC) (Thiffault et al. 2024); DREAM (Royo et al. 2023; Ravn et al. (2024); Wotherspoon et al. (2024)

low-intensity burning is now recognized as a critical tool in Indigenous land stewardship to maintain forest fuels at an acceptable level, thereby reducing the occurrence of catastrophic fires. This approach is now being recognized as a desirable management strategy (Mulverhill et al. 2024), which had previously been applied by Indigenous communities for generations.

By appreciating, respecting and incorporating diverse backgrounds and worldviews we not only provide a more inclusive classroom environment but also provide opportunity to touch on many varying perspectives that will be key in decision-making process and implementation of adaptive silviculture in the future. In doing so, this can also help change some of the negative views of forestry to promote governance (Burgess 2014), not only for Indigenous communities, but to the general public as a whole.

4.5. Complexity, uncertainty, and risk

The inherent uncertainty of global change is resulting in a shift toward adaptive silviculture, which is needed to manage forests in a rapidly changing environment. This includes acknowledging that forests are complex systems; complexity being defined as the balance between the robustness and the adaptability of the forest ecosystem and the level of intricacy and diversity within it. Recognizing that the assessment of current—as well as future—forest resources are uncertain is a way to deemphasize the concepts of stable and predictable forests toward envisioning multiple plausible futures. For this reason, the adaptive approaches of resistance, resilience, and transition (Millar et al. 2007; Nagel et al. 2017; Palik et al. 2022; D'Amato et al. 2023) must be matched with teaching silvicultural strategies incorporating research techniques promoting complex and realistic problem solving (Richards and Robak 2008). These strategies must be adapted toward stands and landscapes to achieve multiple management goals and avoid an "all eggs in one basket" approach. To better understand the trade-off between multi-goal and multi-risk strategies and explore bold and innovative future silvicultural strategies (Bastit et al. 2021), students must understand complex systems science (Puettmann 2011) and their associated risks and uncertainties.

Risk—i.e., the probability of loss or damage to the forests due to different hazards—is an important concept in silvicultural teachings in terms of how to manage the vulnerability of forests with the hazards of global change (Albert et al. 2015). Teaching risk management should highlight important concepts such as (a) multiple concurrent risks, (b) accumulating deleterious effects of disturbance, and (c) multiple scenarios using historical data of frequency, intensity, and spread (Gardiner and Quine 2000). Lessons should incorporate large national and international databases (Gardiner and Quine 2000) to utilize data sources that assess the response of previous silvicultural systems to historical environmental changes. An example of this is using historical or long-term silvicultural case studies and compare original stand objectives and treatments to their resulting outcomes and effectiveness (Müller et al. 2021). Part of risk management will also include understanding the assumptions and limitations of both innovative silvicultural treatments, technologies, and statistics that are used to monitor them over spatial and temporal scales (Gardiner and Quine 2000; Yousefpour et al. 2012).

Risk also requires an understanding of the uncertainty—i.e., incomplete knowledge due to either lack of data, variability in future projections, or unknown components of the decision-making process—of future change, which is rarely included in the silviculture curriculum. In silviculture, this is often quantified using mathematical models that assess risk by assuming parameters with probability distributions or applied stochastic processes that are known (Yousefpour et al. 2012). Examples can be seen in tools analyzing the effectiveness of silviculture treatments to mitigate the risk of wildfire (Johnston et al. 2020), wind damage (i.e., ForestGALES; Gardiner and Quine 2000), and loss of value (CvaR; Müller et al. 2019). Such tools aid in better understanding adaptive silvicultural decision-making with multiple stand objectives such as forest health, biodiversity, resistance, resilience, carbon sequestration potential, and ecosystem service values. Understanding and quantifying uncertainty is a requirement, but understanding how to incorporate it into practice remains a challenge. Without guidance to do so, practitioners may feel frustrated (Lawrence 2017), reiterating the importance of incorporating new teaching techniques so students are equipped to better respond to uncertainty.

Teaching risk management in silviculture requires bridging competencies of risk assessment, uncertainty, and personal adaptive capacity to avoid limiting adaptive measures in silviculture (Knoke et al. 2020). This can be done by using interdisciplinary tools such as adaptation learning supports, which teaches these concepts using skills, foundational knowledge, and social roles. These tools are particularly useful when relevant policies are not yet well defined (Feinstein and Mach 2020). Incorporating learning activities such as serious games (Bengston et al. 2022; Rodela and Speelman 2023; Wallin and Brukas 2024), political dialogue (Burgess 2014; Hess and McAvoy 2014), and Traditional Ecological Knowledge (Jessen et al. 2022) integrates more human dimensions to apply, analyze, and evaluate risk management. Utilized in conjunction with teachings of data-driven silviculture and cutting-edge forestry research, adaptive learning can help bridge professional and foundational skills (Feinstein and Mach 2020).

5. The path forward: a new vision for teaching silviculture

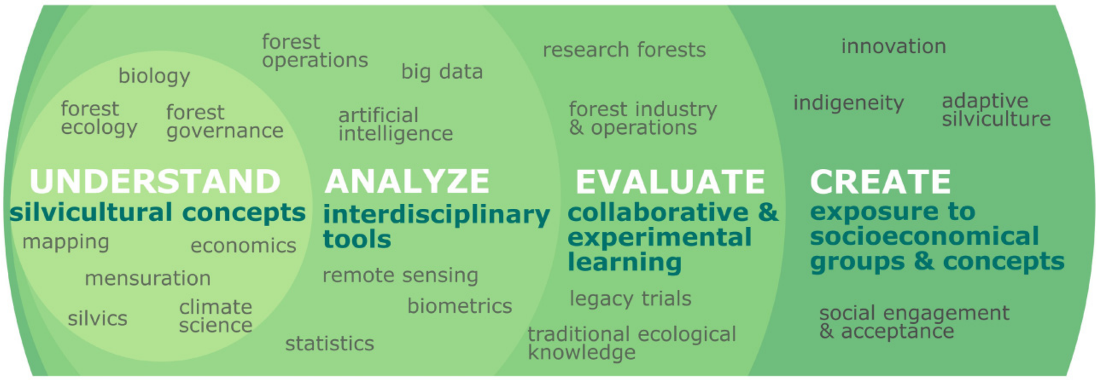
As with many complex fields of teaching, silviculture requires many technical and professional skills from an ever-growing range of disciplines. For students to master these skills and create novel approaches to silviculture, a new vision of teaching silviculture is required (Fig. 3). Given the evolving nature of silviculture as a scientific discipline (Achim et al. 2022; Puettmann et al. 2025), as well as pedagogical development, we propose a path forward that addresses the ongoing challenges with an interdisciplinary, data-driven, and forward-looking approach all while integrating the latest pedagogical concepts of experiential education. In the following section, we propose a new vision of teaching silviculture whereby instructors teach foundational silviculture knowledge (for students to remember and understand) while introducing evolving concepts through experiential education to improve learning (for students to better apply, analyze, and evaluate) to build toward novel silviculture approaches in the future (Fig. 2).

5.1. Embracing experiential education, active learning, and diverse learning opportunities

Silviculture courses are ideal learning environments for experiential education to link foundational knowledge with critical concepts using diverse teaching techniques. During experiential learning, students use multiple neural networks during hands-on activities (compared to a single network during traditional lectures), which results in the creation of new memory pathways. Not only does this aid in recalling relevant course content, it also helps build connections from abstract concepts to real-world scenarios (Schenck and Cruickshank 2015).

Experiential education contains many different methods of teaching including active learning, project- and community-based learning, and integrative learning (Roberts 2015). These include active learning activities—activities that promote

Fig. 3. A new vision for teaching silviculture in undergraduate programs; introducing foundational concepts for students to understand and remember before moving on to more complex concepts to analyze and evaluate. Incorporating a new vision of teaching that includes innovative tools and technologies, interdisciplinary teaching teams, experiential learning, and exposure to socioeconomic drivers will allow students to move toward creating new ideas to implement adaptive silviculture in the face of global change.



student engagement through group work, problem solving, discussions, and/or games (Driessen et al. 2020)—and the use of multimedia so students can learn better through the presentation of words and images/videos simultaneously (Mayer 2008; Sweller et al. 2011) (Table 3). Active learning in the classrooms has been found to improve student exam scores and success rates across all fields of STEM when compared to traditional lecture-style teaching (Freeman et al. 2014). Additionally, activities such as pre-class quizzes, *iClicker* questions, worksheets, group discussions, and practice problems (Table 3), have been found to be disproportionately beneficial to underrepresented or historically marginalized groups including black and first-generation students (Eddy and Hogan 2014) and females (Odom et al. 2021), thereby promoting greater equity among a diverse student body.

Active learning activities not only provide greater flexibility for instructors in producing a more diverse course structure but also opportunities for low-stake assessments for students, which in turn help retain student motivation and promoting a personal growth mindset (Yeager et al. 2019). Activities that encourage students to engage with their classmates also allows them to connect and share their perspectives, learned experiences, and expertise. This helps students develop their professional (or "soft") skills for careers that will likely include multiple stakeholders across the field of silviculture and forest management.

5.2. Innovative tools and new technologies to enhance teaching

To enhance students' classroom experiences, innovative tools and technologies should be integrated into experiential learning activities. This includes not just multimedia tools for teaching, but innovative technologies relevant to silviculture that provide students with hands-on learning opportunities to prepare them for their future career (Table 3). For example, recent advances in remote sensing, growth simulation software, processing capabilities, and virtual reality offer a portfolio of technological tools (de Almeida et al. 2020) that are currently only being utilized to a fraction of their potential in forestry education. These tools are optimal in complementing outdoor education (or use in its place when outdoor activities are not possible) and can be integrated into project- problem- or game-based learning and work-integrated learning activities (Roberts 2015) allowing students to overcome the logistical limitations of field experiences or to experience them on larger scales. For example, field visits can be simulated or enhanced using laser scanning data to enable students to virtually explore areas while also experimenting with new technology, data acquisition, and the manipulation of new data sources in the classroom. These digital representations can be used to overcome challenges of high-cost field visits and to explore more diverse forest stands, and a greater number of silvicultural treatments (Au and Lee 2017; Shen et al. 2019; Culbert 2021).

Training and experience in big data analytics is also likely a hallmark of a future silviculturist (Pappas et al. 2022). Manipulating and analyzing these data, which in the context of silviculture are often geospatial in nature, will require some programming skills and experience (Zou et al. 2019). In this regard, there should be a greater classroom emphasis on understanding, analyzing, and manipulating big datasets, as well as computer models and simulations, rather than considering them strictly as computer-science course material (Table 3). Innovation in teaching in this area is common, with many educators utilizing a variety of online tools, calculators, and demonstrators for these technologies in online labs, computer simulations, and tutorial demonstrations (Wu and Lee 2015). Such exposure for students will build a skillset whereby they gain hands-on learning experience by acquiring, analyzing, and reporting on the data themselves.

Teaching with technology in such ways has the potential to be more cost-effective, safe, inclusive, and efficient compared to traditional methods that require a lot more time for learning activities in the field (Au and Lee 2017; Shen et al. 2019). This is not to say that virtual reality and digital visits should replace boots-on-the-ground experience, but instead

Table 3. Methods of experiential educational content to different stakeholders involved in teaching students' concepts of silviculture.

Experiential education method	University instructor	Forest manager or silviculturist	Landowner or community member
Active learning activities (i.e., case studies, simulations)	Assigns students real-world scenarios (e.g., different harvesting options based on land-owner objectives) and asks them to develop a management plan	Conducts scenario planning and growth modeling for future stand management under changing climate scenarios or potential disturbance factors, engaging with their team	Uses decision-support tools (e.g., growth model projections) to evaluate options for their woodlot
Discussion groups	Facilitates student led discussion on forest policy, ethics in forestry, or emerging silvicultural treatments	Organizes meetings or conferences with interdisciplinary stakeholders to discuss sustainable forest management strategies	Hosts community roundtable events to discuss local forest health, invasive species, or wildfire prevention, and preparedness
Interactive polling, surveys, or quizzes	Uses *iClickers* or pre-class quizzes to gauge students' understanding of ecological concepts and their interactions with silvicultural treatments	Uses mobile survey applications to gather input from field crews on treatment effectiveness	Uses interactive polling by phone, email, community meetings or events to prioritize specific forestry initiatives (e.g., local tree planting programs)
Work-integrated learning activities (i.e., site visits, field tours)	Leads students on field trips or field labs to managed forests where they analyze silvicultural treatments and ecosystem responses	Hosts site visits with industry partners to assess different possible treatment outcomes and share best management practices	Visits demonstration forests or works with partners or extension services to explore different sustainable land management techniques
Multimedia and GIS-based learning activities	Uses ArcGIS and aerial imagery to teach students about forest inventories, landscape dynamics, and land management history	Analyzes remote sensing and LiDAR data to track changes in forest cover over time and plans silvicultural interventions	Uses digital mapping tools to monitor forest conditions to plan harvests or assess ecosystem health
Big data analysis and manipulation	Assigns students large inventory, LiDAR, or climate data to analyze forest dynamics (e.g., forest growth, carbon sequestration potential, or trends in biodiversity)	Uses national forest inventory data, remote sensing data, and growth model projections to optimize forest regeneration over time and monitor regional disturbances	Works with open-source datasets to assess long-term trends in local forests and inform management decisions
Community-based learning and Indigenous partnerships	Engages students in partnerships with Indigenous communities to explore traditional ecological knowledge and its role in silviculture	Collaborates with local communities to integrate traditional ecological knowledge and Indigenous forest stewardship practices into management plans	Participates in local community-led forest restoration projects or Indigenous land stewardship initiatives

Note: GIS, geographic information system.

enhance the learning experience and be used when field visits may not be logistically possible such as in large cities or when far away from appropriate forest stands, which is particularly true for Canada given its vast size and distribution of forest cover. They have the additional benefit of preparing students for likely tools and technologies they will use in future careers and help employers feel confident about the skills of their recent graduate hires (Unger et al. 2018).

5.3. Experiential learning through field courses, co-op programs, and research forests

Work-integrated learning opportunities such as field courses and school, co-op programs, internships, and field placements are great examples of experiential education that can provide students with a diverse range of learning activities (Table 3). In field labs, courses and schools, seeing silviculture on the landscape allows students to take on the role of both observer and participant (i.e., in the role of a landowner or silviculturist) to better connect with course material taught in class. This provides opportunity for reflection from multiple perspectives, which allows them to access multiple cognitive abilities to promote better understanding and problem solving so that they can connect abstract concepts together more easily compared to if they were in a conventional classroom (Schenck and Cruickshank 2015). This cognitive process covers a wide range of learning opportunities that use lived experiences to bridge competencies between the technical, environmental, and human challenges of adaptive silviculture, which is more challenging to achieve through other teaching methods. This will be essential as a part of the new vision for teaching as silviculture becomes increasingly interdisciplinary, requiring students to bridge competencies between a wider range of subject material.

Other work-integrated learning opportunities, such as co-op programs, internships, field placements, or supervised research projects provide opportunities for future forestry students and silviculturists to bridge competencies between academic learning and professional skills required for their careers. It also provides them with an opportunity to engage in authentic and meaningful work experience, which has been found to be particularly true for international compared to domestic students (Nevison et al. 2017). In addition to hands-on experience that will be applicable in future career opportunities, this type of meaningful work positively impacts students' values, beliefs, and motivations, while supporting greater autonomy and productivity (Haddara and Skanes 2007). Co-op programs not only improve the chance of employment and higher earning wages (and more so in STEM compared to arts and social science subjects), but also reduces wage gaps between visible minority, immigrant students, and females compared to white males compared to those who do not participate in such programs (Wyonch 2020). It provides hands-on experience which is often required (or preferred) by government agencies, private industries, and contractors when hiring for forestry positions (Kolb et al. 2014).

In the absence of—or in addition to—work-integrated learning opportunities, universities may have access to university-run and operated research forests. Similar to co-op programs, research forests represent an opportunity to immerse students in innovative forestry practices and involve them in their development, application, and evaluation of silvicultural practices from a research perspective over a longer period of time. These types of research activities, which often involve researchers, practitioners, and local community stakeholders, enable the application of learned concepts in a real-world context (Day et al. 2022) through project-based learning, which includes inquiry- and problem-based learning, as well as experiencing the role of the practitioner and project capstones (Roberts 2015). Undergraduate programs that can promote research forests as an educational tool are likely to pique interests of future students to encourage student enrollment, which would hopefully show their utility to overcome budgetary pressures and the loss of forest facilities worldwide (Prescott 2014). To promote student access, universities and forest research organizations such as the International Union of Forest Research Organizations should continue to dedicate resources to promotion and management of research forests.

All of these activities, particularly course labs and field schools, provide an essential component of experiential education; personal focused reflection. Focused reflection activities come in many forms such as pause, debrief, or journaling with the goal of providing a break from instructions and avoid cognitive overload. Instead, focused reflection activities provide students to think back on what they have learned, what they are taking away from the lesson, and see how activities align with learning objectives (Schnenck and Cruickshank 2015). Guided reflection from instructors using ques such as "what, so what, what now" allow students to better understand their academic and field activities (Karm 2010) from a more critical—and some times interdisciplinary—lens (Brookfield 2017) to promote better understanding of complex subject matter. Guided reflections are particularly helpful for students since they can not always readily identify the different ways in which lessons enhance their understanding.

5.4. Building collaborative teaching teams

Given the diversity of forestry topics, tools, and technologies, the range of skills and knowledge to train the next cohort of future silviculturists is unlikely to rest with a single instructor. But just as the field of forestry is becoming more interdisciplinary and collaborative, so should our teaching efforts. This can include promoting course selection across departmental units, faculties, or even other institutions to allow for adjacent courses to be taught, assessed, and applied practically via interdisciplinary experts.

To ensure students have the best training, universities should support professional development for staff and faculty members to provide higher learning with the most innovative and effective methods to promote active learning (Kim and Maloney 2020). To connect with real-world applications, universities could also encourage their instructors to have relationships, or professional experience, among and within the forestry sector; whether through industry, nongovernmental organizations, etc. This is not only a way to help bridge academia and the job market (Hakamada et al. 2023) but also build relationships within and across institutions. If instructors lack relationships with various stakeholders, they may instead relay outside perspectives by suggesting nonacademic literature and welcoming guest lecturers. Students themselves have shown preference to be taught by those not only with academic experience, but also with professional experience relevant to the current job market, which will likely favor their engagement in the learning process (Kelly and Brown 2019). Such practices can also reduce some of the organizational challenges that exist to ensure various skills are taught at the same level and consistency across year levels and programs.

5.5. Exposure to socioeconomic drivers and concepts through partnerships, collaborations, and community

Forestry programs have previously been criticized for showing discrepancies between the importance and preparedness of the human dimensions of natural resource management, particularly in conflict management and effective communication in the workplace, in public, and with stakeholders (Sample et al. 2015). This likely stems from the lack of emphasis on the importance of diverse perspectives and worldviews in the field of forestry and lack of trusting relationships between universities, educators, and stakeholders. To bridge this gap, silvicultural curricula should highlight diverse perspectives across the field to build trust, relationships, community, and collaborations that will benefit the next cohort of silviculturists, and forestry students and communities as a whole.

Student learning is often driven by individual intrinsic values with feelings of community being a main motivator (Pedler et al. 2022), underscoring the importance of strong relationships between universities, educators, and stakeholders. This includes relationships that promote more diverse teaching units across forestry stakeholders that have become more popular amongst silviculturists, economists and biometricians, geographers, anthropologists, psychologists, planners, business managers, hydrologists, and engineers (Innes and Ward 2010). These relationships and collaborations would allow for better utilization of field courses, co-op programs, and research forests (previously discussed) and provide students a greater experiential learning opportunity of the socioeconomic drivers that underly adaptive silviculture decision-making.

Furthermore, experiential learning involving forestry stakeholders could allow for potential future relationships and collaborations with community forests and Indigenous communities to expand students' understanding of ways in which silviculture can be taught as a tool beyond maximizing production and as a tool to reconcile ecosystem and human needs. Finally, this would provide students with an opportunity to communicate effectively with a wide range of audiences about the role of silviculture in the context of global change and to promote the role forests play as natural climate solutions, which would favor a greater social acceptance of different forms of forest management.

6. Concluding remarks

In times of unprecedented change, which are driving substantial shifts in how we observe forest ecosystems, anticipate their response, and adapt stand structure and composition using traditional and innovative silvicultural practices, we must also alter the way we educate future silviculturists. To address current challenges in teaching silviculture, we must develop a new, interdisciplinary vision that integrates diverse perspectives, and epistemologies. This includes setting the foundations of silviculture early in undergraduate programs so students are able to understand, synthesize, and apply the relevant material in later years of their programs. It is important to remain mindful of foundational skills (such as basic math and statistics) that can be incorporated in new approaches using new tools (i.e., geospatial analysis, risk assessment). At the same time, students must remain open to evolving silvicultural concepts in the face of socioeconomic shifts and global change, which will challenge them to apply new tools and analyze complex scenarios to create novel ideas and decisions in silviculture.

To meet the current challenges of teaching and prepare the next cohort of silviculturists, educators must work to bridge competencies between the many disciplines that encompass the field of silviculture. We posit that the best way to achieve this is through experiential education. Experiential education promotes student learning across all cognitive abilities, especially when incorporating an active learning component that provides students with hands-on activities, group discussion, collaborative projects, and innovative tools and technology. This approach provides students the opportunity to engage with multiple tools and learning pathways, helping them to commit materials to memory, critically analyze subjects, and apply their understandings to novel, real-world scenarios.

Work-integrated learning opportunities such as outdoor labs, field courses and schools, co-op programs, internships, and projects within research forests are essential, providing meaningful work experience that will better prepare students for their future careers. Work-integrated opportunities also enable networking and foster new collaborations with partners outside of academia. These partnerships are essential for connecting student knowledge with the surrounding community and exposing students to diverse worldviews. They also enable students to effectively communicate the role of silviculture in the context of global change and the vital role forests play in a changing climate. With this vision, students will acquire the tools and abilities necessary to synthesize their skills and knowledge into innovative silvicultural solutions.

Acknowledgements

The co-authors of this manuscript respectfully acknowledge that the research and writing for this publication took place in many institutions situated on traditional, ancestral—and often unceded—lands of Indigenous peoples across Canada. We honour the long-standing relationships with these lands, forests, and ecosystems and recognize the deep knowledge systems that have sustained them over millennia. We remain committed to fostering respectful and meaningful relationships and acts of reconciliation. This research was funded by Silva21, a NSERC Alliance research program (NSERC ALLRP 556265-20) led by Alexis Achim (Université Laval, Québec). Thank you to Catherine Chagnon (Université Laval) for creating the figures for this manuscript.

Article information

History dates

Received: 19 March 2025
Accepted: 11 June 2025
Version of record online: 28 July 2025

Copyright

Data availability

This manuscript does not report data.

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Nelson Thiffault served as Co-Editor-in-Chief and Ignacio Barbeito and Alexandre Morin-Bernard as Associate Editors at the time of manuscript review and acceptance; peer review and editorial decisions regarding this manuscript were handled by another editorial board member.

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Conceptualization: ARW, GM, AM-B, AA, NCC, OV
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Writing – review & editing: ARW, GM, AM-B, AA, NCC, OV, LAKI, SH, NT, CC, BNIE, IB, JW, VR

Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/cjfr-2025-0081.

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