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Shared goals in science education: youth agency across three national systems

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Abstract

Science education faces a constant challenge across national contexts: sustaining adolescents' engagement while supporting rigorous disciplinary learning. This paper conceptualizes science curriculum as an opportunity structure that shapes how young people participate in disciplinary sense-making, experience recognition, and maintain future pathways. Using a qualitative comparative document analysis, we examine how the national science curricula in Colombia, Estonia, and the United States articulate disciplinary learning, opportunities for youth agency through inquiry and hands-on or project-based learning, and assessment practices that make learning visible. Drawing on the curriculum theory and sociocultural perspectives, agency is treated not as an individual trait but as an emergent outcome of task design, participation structures, and recognition practices embedded in curricular guidance. In the three cases, curricula share commitments to inquiry and relevance but operationalize them through distinct configurations: US frameworks focus on participation in scientific practices through three-dimensional learning, Estonia emphasizes autonomy and self-regulated inquiry as central to scientific literacy, and Colombia highlights science learning in everyday life and community concerns. We argue that engagement precedes aspiration: curricula that structure sustained sense-making through coherent projects, inclusive participation conditions, and formative assessment can support adolescents' competence, belonging, and purpose, enabling diverse life trajectories beyond narrow STEM pipelines.

Keywords: science curriculum, youth agency, inquiry-based learning, project-based learning, comparative education

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Introduction

Science education is widely seen as an essential preparation for life in societies shaped by scientific and technological change. During adolescence, this preparation becomes especially consequential. Young people face increasing cognitive demands, heightened sensitivity to peer recognition and belonging, and increasing questions about identity and future pathways (Eccles & Wigfield, 2002; Steinberg, 2014). In this developmental period, science curriculum operates not only as an organized sequence of disciplinary concepts but also as a social and political text that mediates access to participation, recognition, and valued forms of knowledge (Apple, 1996; Pinar, 2012). How science is framed and structured – what counts as legitimate participation, which problems are positioned as worthy of investigation, and how students' ideas are taken up – shapes whether adolescents experience science as meaningful and inclusive or as distant and exclusionary.

Across national contexts, sustaining adolescents' engagement in secondary science remains a persistent challenge. Scholars have documented how many students experience school science as abstract, overly technical, or disconnected from everyday concerns, with engagement often declining as content becomes more specialized in advanced secondary school courses (Archer et al., 2012; Osborne et al., 2003). These patterns are consequential because disengagement is closely tied to opportunity structures that shape access to postsecondary education and science majors, recognition as "science-capable," and the ability to imagine science as relevant to future career possibilities (Archer et al., 2012; Carlone & Johnson, 2007). The core issue is not adolescents' capacity to learn complex ideas, but whether science learning environments provide problems designed to support sustained sense-making – figuring out phenomena, coordinating evidence and explanations, and revising ideas (Schneider et al., 2022). Research indicates that engagement and learning increase when instruction supports iterative investigative problems, modeling, and explanation, rather than emphasizing content exposure alone (Xiao & Schneider, 2023; Krajcik et al., 2023).

In this study, engagement in science learning is defined as students' active involvement in disciplinary activity, encompassing cognitive participation in sense-making, affective investment in learning tasks, and social participation in collaborative inquiry. From this perspective, engagement is understood as a situated experience that varies with instructional activity rather than as a stable student disposition (Avraamidou, 2019; Carlone & Johnson, 2007; Gutiérrez & Calabrese Barton, 2015; Schneider et al., 2022). Research consistently shows that adolescents report higher engagement during learning experiences that involve

hands-on investigation, explanation, and collaborative sense-making – activities through which engagement is enacted – compared to more passive instructional formats (Schneider et al., 2016; Xiao & Schneider, 2023).

In this paper, sense-making refers to the process through which students actively interpret phenomena, construct and revise explanations, and conceptualize evidence, models, and scientific ideas, and is not treated as an individual cognitive skill but as a socially organized practice embedded in instructional tasks and participation structures (Schneider et al., 2020). Scientific practices support engagement when they immerse students in coherent tasks that allow them to contribute ideas, experience progress, and refine explanations across learning episodes (Schneider et al., 2020). These opportunities are understood as expressions of youth agency. From sociocultural perspectives, agency is not a singular personal characteristic but an emergent property of participation in socially organized activity, shaped by task design, norms, and recognition practices (Holland, 2001; Nasir et al., 2006). This framing shifts attention away from motivating individual students toward examining how curriculum designs structure conditions for meaningful participation.

Designing for this form of participation requires more than adding hands-on activities. Project-based and inquiry-oriented learning environments support durable engagement when they organize learning around sustained sense-making and evidence-based reasoning (Blumenfeld et al., 1991). When aligned with formative assessment and clear learning goals, these environments support adolescents' developing sense of competence and engagement (Eccles & Wigfield, 2002; Pellegrino, 2015). On the other hand, opportunities for sense-making, engagement, and agency are shaped by how curricula draw on students' cultural resources – including everyday experiences, linguistic repertoires, community and intergenerational practices, and social concerns – as legitimate starting points for inquiry. Scholarship on culturally relevant, responsive, and sustaining pedagogies conceptualizes these resources as mediating tools that expand access to disciplinary reasoning and participation, rather than as alternatives to scientific knowledge (Ladson-Billings, 1995; Nasir et al., 2006; Bang & Medin, 2010; Paris, 2012; Gay, 2023; Mathis et al., 2023; Valbuena Rojas & Krajcik, 2025).

The purpose of this paper is to examine *how national science curricula in Colombia, Estonia, and the United States conceptualize disciplinary learning in ways that support youth agency and engagement during adolescence, with particular attention to cultural resources and hands-on and project-based learning*. Through comparative document analysis and by discussing agency as a universal developmental process shaped by curricular opportunity structures, this study contributes to international curriculum conversations on designing science education that is rigorous, meaningful, and broadly accessible.

Curriculum, youth agency, and hands-on disciplinary learning

In this study, youth agency is defined as the emergent capacity to participate meaningfully in disciplinary practices, developed through structured, culturally responsive, inquiry-rich learning environments in which students' contributions, identities, and experiences are recognized (Holland et al., 2001; Nasir et al., 2006; Gutiérrez & Calabrese Barton, 2015). Agency is social rather than individual, enacted rather than possessed, and shaped by curriculum design choices that structure participation, recognition, and feedback. This definition provides the analytic lens for examining how curriculum documents articulate opportunities for participation and sense-making.

This analysis is guided by a conceptual framework that positions science curriculum as a central mediating structure through which youth agency, engagement, and disciplinary learning are made possible during adolescence. Three interrelated dimensions are explored: (a) curriculum design as a bridge between disciplinary knowledge and students' lived experiences as part of their cultural resources; (b) youth agency as an experiential and relational outcome of learning environments; and (c) hands-on and project-based learning as a key mechanism through which disciplinary understanding and engagement are cultivated.

Curriculum design and purpose: bridging disciplinary knowledge and experience

Science curriculum can be understood as a bridge. It does not merely transmit disciplinary knowledge but connects universal scientific ideas and practices to learners' experiences and cultural resources. Aikenhead (2006) argues that meaningful science education supports students in navigating between the culture of school science and the everyday contexts and practices in which they live. This bridging function does not require redefining scientific knowledge or weakening disciplinary rigor. Instead, it involves designing curricular entry points, including specifying phenomena, questions, problems, and investigations grounded in recognizable contexts. By engaging in these activities, students can access scientific reasoning through experiences that feel relevant and purposeful.

National curriculum frameworks reflect this bridging function through different design practices. In the US, standards-based reforms such as the Framework for K–12 Science Education emphasize coherence and progression, foregrounding scientific practices and core ideas to engage students in doing

science rather than memorizing content (National Research Council [NRC], 2012). Estonia's national curriculum frames science education as a means of supporting students' personal development and societal participation through shared cultural and civic goals (Holbrook & Rannikmäe, 2009; Kori, 2022). In Colombia, national guidelines encourage teachers to connect science learning to community contexts and locally meaningful knowledge that students recognize from their daily lives (Ministerio de Educación Nacional [MEN], 1998). Although these systems differ in structure and implementation, they share an orientation toward curriculum as a mechanism for agency and engagement.

Together, these countries all view curriculum as an equalizer of access, mediating who can participate in meaningful science learning and under what conditions. Students enter science classrooms with unequal exposure to scientific practices, academic language, and the implicit norms that govern how knowledge is produced and evaluated in school science. These inequalities are not reducible to individual ability; rather, they reflect differences in prior schooling, family resources, access to informal science experiences, and alignment between students' cultural resources and institutional expectations (Lee & Buxton, 2013; Nasir et al., 2006). As a result, traditional curricula that rely on abstraction, decontextualized problem sets, or implicit norms of participation often privilege students who already possess the cultural and academic capital aligned with school science.

However, when curricula are designed around investigation, explanation, and iterative sense-making, they can mitigate these disparities by making disciplinary participation explicit and accessible through shared, culturally recognizable entry points. Previous research demonstrates that engaging students in shared problems, observable phenomena, and collaborative inquiry provides common reference points for participation, regardless of students' prior familiarity with scientific conventions (Blumenfeld et al., 1991; National Research Council, 2012). In these environments, disciplinary practices are not assumed to be already mastered but are introduced, modeled, and revisited through structured learning sequences.

This shift holds important implications for how students are positioned in relation to science. When curricula provide repeated opportunities to ask questions, test ideas, and revise explanations, students are positioned as capable sense-makers whose contributions and ways of knowing are taken seriously within disciplinary activity. Such environments foster engagement by enabling students to experience competence and progress through participation in meaningful tasks (Schneider et al., 2020). By contrast, curricula that prioritize coverage and correctness without making disciplinary practices accessible often reinforce existing hierarchies of recognition, signaling to some students that

science is "not for them." From a sociocultural perspective, a critical precondition for the development of youth agency emerges when students perceive that their ideas matter and that they have a legitimate role in the learning process (Holland, 2001). By equalizing access to disciplinary practices and recognizing students' cultural resources, the curriculum creates structural conditions under which students can take intellectual risks, exercise decision-making, and reflect on their learning. In this sense, curriculum functions as a bridge between disciplinary knowledge and youth agency, linking access to scientific reasoning with opportunities for ownership and participation.

Youth agency as a learning experience

Youth agency is central to understanding how adolescents engage with the science curriculum and how they experience learning as a meaningful participation. Research in science education consistently shows that students' engagement and persistence are closely linked to whether they experience recognition and intellectual responsibility in disciplinary activity (Carlone & Johnson, 2007; Nasir et al., 2006). These dynamics are particularly salient during adolescence, when sensitivity to autonomy, competence, and belonging intensifies (Eccles & Wigfield, 2002).

Within science learning environments, agency is enacted through task design, participation structures, and assessment practices that signal whose ideas matter and how progress is recognized. Studies demonstrate that when students are positioned as active contributors – asking questions, testing ideas, and revising explanations – they are more likely to sustain engagement and develop confidence in their ability to reason scientifically (Reeve, 2012; Schneider et al., 2020). Importantly, agency in this sense does not imply unstructured choice; instead, it depends on carefully designed tasks and clear expectations that support students in taking intellectual risks while remaining oriented toward shared learning goals.

Beyond classroom engagement, youth agency in science education carries broader implications regarding how adolescents understand their role in society. Scientific literacy increasingly underpins participation in civic, political, and economic decision-making, particularly around issues such as public health, environmental sustainability, and technological change (Maltese & Tai, 2011; Sadler et al., 2012; Feinstein et al., 2013; OECD, 2018). When science curricula support agency, they enable students to view scientific reasoning as a resource for interpreting information, evaluating claims, and responding to issues that affect their communities. In this way, agency in science learning contributes to critical literacy and informed participation, even for students who do not envision futures in scientific careers.

Research on project-based and inquiry-oriented learning highlights how agency-supporting environments position students as problem-solvers working on meaningful questions. For example, technology-supported and problem-based learning environments have been shown to foster civic engagement by enabling students to investigate real-world problems, collaborate with peers, and propose evidence-based solutions (Schneider, 2017; Schneider et al., 2020). These experiences reinforce the relevance of scientific practices beyond school and strengthen students' sense of purpose in learning.

The role of curriculum design is therefore central to how agency is experienced. Curriculum guidelines shape whether agency is treated as incidental or as a systematic outcome of instruction by specifying the kinds of tasks students engage in, the norms governing participation, and the criteria used to evaluate learning. When curricula clearly articulate expectations for inquiry, collaboration, and reflection, they provide teachers with structural support for cultivating agency consistently across classrooms (Krajcik & Blumenfeld, 2006).

Taken together, this body of research suggests that youth agency develops when students experience participation, ownership, and feedback as integral to disciplinary work. Recognizing youth agency as a learning experience underscores the importance of curriculum designs that make participation visible, significant, and accessible during adolescence.

Hands-on and project-based learning as mechanisms for disciplinary engagement

Hands-on and project-based learning (PBL) constitute a central mechanism through which curriculum design supports disciplinary engagement in science education. Research across the learning sciences consistently demonstrates that students develop deeper and more durable understanding when they actively engage in disciplinary practices – such as framing problems, designing investigations, analyzing data, and constructing explanations – rather than encountering scientific knowledge primarily through exposition or procedural exercises (Blumenfeld et al., 1991; Krajcik & Blumenfeld, 2006; Valbuena Rojas & Krajcik, 2025). From this perspective, engaging in the practices of science is a primary pathway to understanding science, not an enrichment layered onto content instruction.

Project-based learning (PBL) is particularly effective for disciplinary engagement because it organizes instruction around extended, coherent investigations that require sustained reasoning over time. Well-designed PBL systems focus on problem framing, iterative sense-making, and the application of disciplinary ideas to novel contexts. He, Krajcik, and Schneider (2023) show that coherent PBL designs can translate standards into classroom practice by supporting

knowledge-in-use – students' ability to mobilize concepts and practices to explain phenomena and solve problems. When projects are carefully sequenced, scaffolded, and aligned with learning goals, PBL environments promote both disciplinary understanding and sustained engagement across diverse classrooms.

Importantly, hands-on and project-based learning are not synonymous with open-ended exploration or playful activity. Although interest and motivation are important outcomes, the defining feature of PBL lies in its epistemic structure (Blumenfeld et al., 1991; Krajcik & Blumenfeld, 2006). Projects require students to engage with authentic problems that demand evidence-based reasoning, collaboration, and revision of ideas (Krajcik et al., 2022; He et al., 2023). Through these demands, PBL supports multiple literacies by integrating scientific reasoning with communication, collaboration, and critical thinking competencies that are increasingly necessary for participation in contemporary societies (Feinstein et al., 2013; OECD, 2019; Schneider et al., 2020).

Within these structured learning environments, youth agency operates as a mechanism that enables disciplinary engagement. PBL positions students as decision-makers who must determine how to investigate a problem, what evidence is relevant, and how explanations should be constructed and communicated. These decisions are central to the learning process and create concrete opportunities for students to participate meaningfully in disciplinary sensemaking. Schneider et al. (2020) argue that such environments foster engagement by allowing students to experience competence, progress, and purpose through participation in meaningful scientific work.

Hands-on and project-based learning also extends disciplinary engagement by connecting scientific practices to community-relevant and socially significant issues. When projects are oriented toward environmental challenges, public health concerns, or local technological problems, students encounter science as a tool for understanding and responding to their communities, drawing on and building from their cultural resources. Research into PBL shows that these experiences support local and civic engagement by enabling students to investigate real-world problems, collaborate with peers, and propose evidence-informed solutions (Schneider, 2016; Feinstein et al., 2013; Valbuena Rojas & Krajcik, 2025). Such engagements reinforce the relevance of disciplinary science beyond academic success and contribute to broader forms of critical literacy and democratic participation.

In this sense, assessment practices play a critical role in sustaining disciplinary engagement within PBL environments. Performance-based assessments and analytic rubrics make students' reasoning visible and provide feedback that gradually supports improvement (Pellegrino, 2015). When assessment is

aligned with project-based learning, it reinforces the value of participation, revision, and sense-making alongside correctness. This alignment is particularly important for equity, as it reduces the reliance on prior familiarity with academic norms and provides multiple entry points for demonstrating understanding. In this way, assessment supports sustained disciplinary engagement while also reinforcing students' participation and ownership in scientific work.

Together, hands-on and PBL function as a critical mechanism for disciplinary engagement by making scientific participation visible, accessible, and meaningful. By structuring extended opportunities for sense-making, decision-making, and revision, these approaches support engagement as an outcome of disciplinary work, and they position science learning as a foundational life skill that supports diverse pathways, including – but not limited to – scientific careers.

Methodology and analytical focus

This study adopts a qualitative comparative approach to examine how national science curricula in Colombia, Estonia, and the US operationalize disciplinary learning, youth agency, and engagement through hands-on and project-based learning.

Comparative orientation

Comparative curriculum research emphasizes the importance of moving beyond surface-level comparisons to examine how educational systems address shared challenges through contextually situated strategies (Bartlett & Vavrus, 2016). In science education, one shared challenge is sustaining adolescents' engagement while supporting rigorous disciplinary learning. Colombia, Estonia, and the US provide analytically useful cases because they represent distinct historical, cultural, and policy contexts, yet all articulate curricular commitments to inquiry, relevance, and student participation in science. This study does not treat these national systems as competing models or rank them in terms of quality. Instead, the comparison aims to identify shared curricular principles that support youth agency and engagement, as well as context-specific expressions of those principles, contributing to international conversations about curriculum design that transcend national boundaries while remaining sensitive to local conditions.

The primary data sources for this study consist of official national curriculum documents and framework texts governing science education at the upper secondary level in those countries.

Table 1. Primary data sources from each country

Country	Main document	Description
US	*Framework for K–12 Science Education* (National Research Council, 2012) and associated NGSS-aligned curriculum guidance materials	Articulate expectations for three-dimensional learning and engagement with scientific practices
Estonia	National Curriculum for Upper Secondary Schools, Appendix 4, Subject Field: Natural Science (2014) and other science curriculum documents	Highlight inquiry, self-regulated learning, and scientific literacy, as well as supporting scholarship analyzing Estonia's science education reforms
Colombia	*Lineamientos Curriculares de Ciencias Naturales*, issued by the Ministerio de Educación Nacional (MEN, 1998),	Emphasize learning connected to everyday life, social contexts, and community-relevant issues.

These documents are discussed as representations of intended curriculum, recognizing that enacted curriculum may vary in schools and classrooms. The analysis, therefore, focuses on how opportunities for agency and engagement are *conceptualized and structured* at the policy level, rather than how they are implemented in practice. Guided by the conceptual framework outlined in the previous section, the analysis centers on three interrelated analytical dimensions:

1. *Conceptualization of disciplinary knowledge:* How is scientific knowledge framed – facts, practices, or sense-making tied to phenomena and problems?
2. *Structuring of youth agency and participation:* How are students positioned (questioning, decision-making, collaboration, responsibility)?
3. *Assessment and feedback practices:* How is assessment framed to support or constrain agency (formative feedback, performance-based reasoning, visibility of progress)?

Coding scheme and unit of analysis

For analysis purposes, we developed a deductive coding scheme aligned with the conceptual framework and the study's analytic questions. The unit of analysis is a *policy statement* (sentence or short paragraph) that articulates indicators for the codes in Table 2. Codes are applied across documents to identify how curriculum documents articulate opportunities for participation, decision-making, agency, and sense-making during adolescence; codes are used as representation to organize and not to measure exhaustive presence or lack of these dimensions.

Table 2. Coding scheme (core codes, definitions, and indicators).

Core code	Definition	Indicators
Code 1: Disciplinary sense-making (DSM)	How the curriculum frames science learning as explaining phenomena using evidence and models.	Explaining phenomena, modeling, evidence, revising explanations.
Code 2: Youth agency/participation (YAP)	How the curriculum positions students as decision-makers, collaborators, and responsible participants in inquiry.	Student decision-making, responsibility, collaboration, autonomy, inquiry.
Code 3: Relevance & lived experience (RL)	How the curriculum connects learning to everyday contexts, community issues, and students' lifeworlds.	Everyday life, environment, community issues, "lifeworld."
Code 4: Equity as access to participation (EQ)	How the curriculum constructs inclusive conditions for participation.	Inclusion, participation conditions, differentiated tasks, legitimacy of participation.
Code 5: Assessment & visibility of learning (AS)	How assessment is framed to make learning progress and reasoning visible.	Assessment criteria, formative feedback, performance/skills, visibility of progress.

Figure 1 illustrates how the three analytical dimensions guide the study's conceptual focus, how five deductive codes operationalize these dimensions during document analysis, and how multiple codes are synthesized into three interpretive sections. Each section compiles a targeted excerpting strategy: for each code, we select 1–2 short excerpts per country that (a) explicitly named the construct, (b) represented a recurring emphasis in the document, and (c) could function as an anchor quote to justify the interpretation.

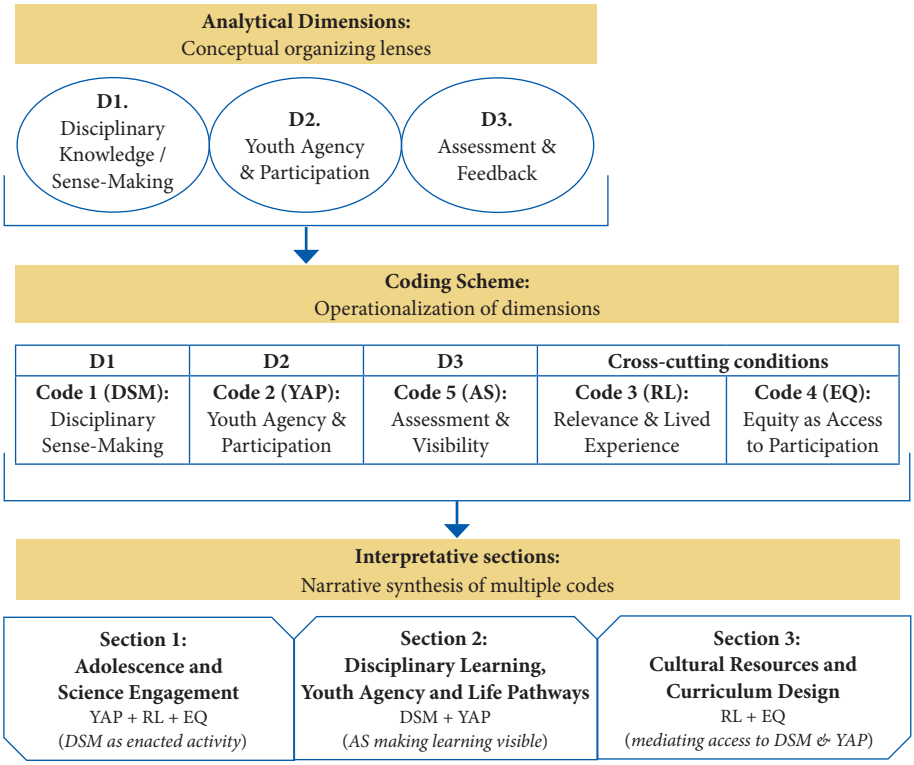

Figure 1. Analytical framework linking dimensions, codes, and findings sections.
Note. Figure developed by the authors for this study.

Analytical scope and limitations

Several limitations to this approach should be acknowledged. First, the analysis is based on curriculum documents rather than classroom observations or teacher interviews. As a result, it cannot account for variability in curriculum enactment in schools and regions. Second, the focus on upper secondary school education means that insights may not fully capture earlier developmental stages. Finally, while the selected cases provide useful comparative leverage, they do not represent the full diversity of global science education systems. Despite these limitations, document-based comparative analysis offers a valuable lens for examining how educational systems conceptualize engagement and agency at the level of the intended curriculum. It is alsoimportant to recognize that these governmental documents are often used in many countries as an accountability bar for determining successful curricular enactment derived from a variety of country-wide testing programs (Pinar, 2012; Penuel & Spillane, 2014; OECD, 2019).

Adolescence and science engagement

Adolescence represents a shared developmental context across education systems in which students' engagement with science is particularly sensitive to how learning opportunities are structured. At the secondary level, science curriculum functions as a key site where adolescents encounter increasing intellectual demands alongside expectations for participation, autonomy, and recognition (Eccles & Wigfield, 2002; Steinberg, 2014). Across the three national curricula under examination, engagement is constructed through different configurations of relevance to lived experience (RL), youth agency and participation (YAP), equity as access to participation (EQ), disciplinary sense-making enacted through activity (DSM), and assessment practices that make learning visible (AS).

In the Colombian curriculum, adolescent engagement is strongly grounded in RL and collective purpose. The *Lineamientos Curriculares de Ciencias Naturales* frame science learning as *educación para la vida*, emphasizing that students should use scientific knowledge to *interpret and act upon situations related to health*, *environment*, and *social well-being* (MEN, 1998). This orientation positions engagement around participation in socially consequential problems that are recognizable within students' communities. DSM is enacted through contextualized inquiry, as students are expected to explain phenomena drawn from their surroundings, such as environmental quality or public health conditions. While this approach legitimizes students' experiences as meaningful entry points into science learning, structures for YAP and AS are articulated in broad terms, leaving decisions about participation, feedback, and monitoring of progress largely to local interpretation.

In the United States, adolescent engagement is articulated most explicitly through DSM and YAP embedded in scientific practices. The Framework for K–12 Science Education emphasizes that students should actively engage in *asking questions and defining problems*, *developing and using models*, and *constructing explanations and designing solutions* (National Research Council [NRC], 2012). These expectations position adolescents as active sense-makers whose engagement emerges through sustained participation in scientific work. YAP is operationalized through inquiry and argumentation, with performance expectations clarifying how students apply scientific knowledge. AS are foregrounded through an emphasis on evidence-based reasoning and progress over time. RL is addressed through phenomena-based instruction, which provides shared reference points for participation, while EQ is framed primarily through common access to disciplinary practices rather than differentiated participation structures.

Estonia's national science curriculum conceptualizes adolescent engagement through autonomy and self-regulation, closely linked to DSM. Grounded in a strong emphasis on scientific literacy, the curriculum frames science learning as a means of supporting intellectual independence and lifelong learning (Holbrook & Rannikmäe, 2009; Kori, 2022). Adolescents are expected to assume increasing responsibility for planning, monitoring, and evaluating their learning. The curriculum emphasizes that students should *plan investigations*, *analyze results*, and *evaluate conclusions independently* (Estonian Ministry of Education and Research, 2014), positioning engagement as a function of intellectual ownership. AS prioritize reflection and evaluation of the learning processes, supporting the visibility of reasoning. RL is expressed through broad societal themes such as sustainability and scientific literacy, while EQ is addressed implicitly through expectations of participation in shared learning goals.

Across all three contexts, adolescent engagement is constructed through different emphases on shared mechanisms. Colombia focuses on relevance and social purpose (RL), the United States emphasizes disciplinary participation and visible performance (DSM, YAP, AS), and Estonia prioritizes autonomy and self-regulation as conditions for engagement (YAP, DSM). Despite these differences, all three curricula recognize that engagement depends on learning environments that position adolescents as capable participants in sense-making processes.

These patterns suggest that engagement is not a singular curricular feature, but a composite outcome shaped by how relevance, participation structures, equity, and disciplinary activity are coordinated. Science education is framed across contexts as foundational for community futures, supporting informed decision-making, civic participation, and lifelong learning. By embedding engagement within meaningful activity and recognizable contexts, national curricula construct adolescence as a period not only for learning science, but for learning how to participate in knowledge-building in local settings.

Disciplinary learning, youth agency, and life pathways

Among national contexts, science curricula articulate distinct relationships between disciplinary learning and future life pathways, reflecting different educational traditions and societal expectations. In the United States, secondary science curricula are closely connected to postsecondary preparation through advanced coursework and credentialing structures such as Advanced Placement and other college-preparatory pathways. The NGSS framework emphasizes disciplinary practices and performance expectations that align with academic

progression in science and engineering fields, foregrounding DSM as preparation for future participation in scientific and technical domains (National Research Council [NRC], 2012). The Framework for K–12 Science Education states that students should be prepared to *engage in public discussions on science-related issues* and to *apply scientific knowledge to personal and societal decision-making* (NRC, 2012), positioning YAP as the ability to use evidence, models, and explanations in context.

At the same time, the relationship between engagement and aspiration in the US context remains shaped by opportunity structures beyond curriculum texts. Research indicates that access to advanced science coursework is uneven and often stratified by socioeconomic status and school resources (Banilower et al., 2018). While the intended curriculum clearly articulates future-oriented disciplinary participation through DSM and YAP, adolescents' opportunities to translate engagement into concrete pathways depend heavily on local conditions of enactment. AS structures that make reasoning visible are emphasized in policy, but their impact on life pathways is mediated by differential access to instructional resources.

In Estonia, disciplinary learning is framed more explicitly as preparation for lifelong learning and informed participation in a knowledge-based society. National curriculum documents emphasize scientific literacy, self-regulated learning, and the transferability of scientific reasoning across domains (Holbrook & Rannikmäe, 2009; Kori, 2022). The upper secondary curriculum specifies that science education should enable students to *apply scientific methods when solving problems in unfamiliar situations* and to *evaluate information critically in everyday and societal contexts* (Estonian Ministry of Education and Research, 2014). These statements position DSM as a transferable capacity that supports flexible life trajectories.

YAP in the Estonian curriculum is articulated through autonomy and responsibility for learning processes. Students are expected to *plan investigations*, *analyze results*, and *assess their own learning processes* (Estonian Ministry of Education and Research, 2014), framing agency as sustained intellectual ownership. AS emphasize reflection and evaluation of learning processes, reinforcing the students' capacity to monitor progress and apply scientific reasoning to all future academic, civic, and professional contexts.

Colombia's curriculum articulates a different relationship between science learning and future pathways, grounded in social participation and collective well-being. National guidelines frame science education as foundational for understanding environmental, health, and social challenges that shape students' lives (MEN, 1998). Their guidelines emphasize that science education should enable students to *understand their reality and participate responsibly in*

its transformation (MEN, 1998), positioning DSM as a resource for interpreting local phenomena and supporting informed action.

YAP in the Colombian curriculum is oriented toward community responsiveness and social responsibility. Students are encouraged to *use scientific knowledge to address problems related to health*, *environment*, and *quality of life* (MEN, 1998), linking engagement with science to participation in socially meaningful decision-making. While AS are articulated less explicitly, engagement with disciplinary learning supports adolescents' capacity to navigate everyday challenges and contribute to shared futures, even when scientific careers are not an explicit endpoint.

A common principle emerges from the three systems: namely, engagement goes beyond a career aspiration. Curricula that coordinate DSM, YAP, and AS help keep multiple pathways open, including STEM careers as well as domains such as policy, education, environmental management, and health. These patterns highlight the importance of curriculum designs that prioritize participation and sense-making across adolescence. All three curricula recognize that sustained engagement through agency-supporting disciplinary experiences is essential for enabling diverse and meaningful life trajectories.

Cultural resources and curriculum design

Cultural resources play a critical role in shaping how adolescents engage with science learning, particularly when curricula aim to support RL, EQ, and sustained agency. Cultural resources are understood broadly as the everyday experiences, linguistic repertoires, community practices, environmental interactions, and social concerns that students bring into the classroom. Scholarship on culturally relevant, responsive, and sustaining pedagogies emphasizes that these resources function as mediating tools that support access to DSM and YAP, rather than as alternatives to disciplinary knowledge (Ladson-Billings, 1995; Paris, 2012; Gay, 2023; Mathis & Southerland, 2022). From a curriculum design perspective, the inclusion of cultural resources reflects deliberate choices about whose experiences are recognized, how learning is initiated, and how students are positioned as legitimate contributors to scientific inquiry.

Curricula that position students' lived experiences as authentic starting points for inquiry create conditions under which adolescents can engage academically without distancing themselves from their cultural identities. Research consistently shows that when curricula legitimize everyday contexts – such as local environmental conditions, community health issues, or familiar technologies – students are more likely to participate confidently and sustain engagement in disciplinary practices (Nasir et al., 2006; Ladson-Billings, 1995; Gay,

2023). Project-based learning environments are particularly conducive to this process because they allow students to mobilize familiar ways of reasoning within structured investigations, supporting agency and recognition through meaningful contribution (Krajcik et al., 2023; Schneider et al., 2020; Valbuena Rojas & Krajcik, 2025).

In Colombia, cultural resources function as explicit contextual anchors for learning. Their guidelines emphasize science education as a means for understanding and responding to environmental, health, and social issues that are visible in students' communities (MEN, 1998). This orientation strongly supports RL by framing disciplinary learning around problems that matter to adolescents' everyday lives and collective responsibilities. Environmental observations, community practices, and local challenges function as recurring sources of inquiry, allowing students to connect scientific explanations to familiar contexts. While this approach supports inclusive participation (EQ) by legitimizing students' experiences, connections between these contexts and specific DSM and assessment structures remain less explicit, placing greater responsibility on teachers to mediate agency-supporting learning sequences (Gay, 2023).

In the United States, cultural resources are incorporated primarily through phenomena-based instruction, which serves as a shared experiential entry point into DSM. The NGSS framework emphasizes anchoring learning in observable phenomena drawn from everyday experiences, creating common reference points that invite participation from diverse student populations (National Research Council, 2012). This design supports RL by reducing reliance on prior academic exposure and encouraging students to explain events they can observe or experience. EQ is addressed through shared access to practices and phenomena, though guidance on connecting instruction to students' specific cultural or community contexts is less systematically articulated. As a result, cultural resources are often activated through teacher decision-making rather than structurally embedded within curriculum sequences (Paris, 2012; Gay, 2023).

In Estonia, cultural resources are mobilized through shared societal themes such as sustainability, environmental responsibility, and innovation. Science education is framed as central to informed citizenship and long-term societal development, positioning adolescents as future contributors to collective well-being (Holbrook & Rannikmäe, 2009; Kori, 2022). This orientation supports RL at a national level by linking learning to widely shared values, while inquiry and self-regulated learning structures support YAP and access to DSM. EQ is addressed through a strong emphasis on coherence and participation in common learning goals, although connections to students' immediate, localized experiences are often left implicit and mediated through instructional design.

Overall, cultural resources function as mediators of youth agency by shaping how students enter, participate in, and sustain engagement with scientific sense-making. When curricula recognize students' experiences as legitimate foundations for inquiry, they expand access to participation (Nasir et al., 2006; Schneider et al., 2020; Mathis et al., 2023; Valbuena Rojas & Krajcik, 2025). Although the forms of contextualization vary across Colombia, the United States, and Estonia, the underlying function of cultural resources is shared: to ground science learning in lived experience while supporting equitable participation, agency, and sustained engagement across adolescence and communities.

Discussion and implications

This paper supports the argument that science curriculum functions as an opportunity structure for youth agency during adolescence by shaping how students are invited to participate in disciplinary sense-making, how relevance is established, and how engagement is sustained. In Colombia, Estonia, and the United States, national curricula differ in emphasis and structure, yet all address a shared developmental challenge: adolescents are more likely to engage when learning environments support autonomy, competence, belonging, and purpose (Eccles & Wigfield, 2002; Steinberg, 2014). The purpose of this comparison is not to identify a best curriculum model, but to surface design commitments that keep open pathways into scientific reasoning for diverse learners and diverse futures (Maltese & Tai, 2011; Sadler et al., 2012; Mathis et al., 2023).

A central implication is that youth agency should be understood as an outcome of curriculum design rather than as an individual trait students bring or lack. Curriculum guidelines play a critical role in shaping these conditions by clarifying expectations for inquiry, defining students' roles in knowledge construction, and legitimizing students' questions and experiences as starting points for disciplinary work (Nasir et al., 2006). When such conditions remain implicit, opportunities for agency become more dependent on local interpretation and teacher capacity, increasing variability in students' access to meaningful participation.

Across the three systems, sustaining adolescent engagement requires integrating disciplinary learning with participation structures rather than emphasizing content progression alone. In the United States, three-dimensional learning highlights practices such as modeling, explanation, and argumentation as central to learning science, making participation visible and expected (National Research Council [NRC], 2012). Estonia's emphasis on inquiry and self-regulated learning similarly positions adolescents as increasingly responsible for planning and evaluating their learning, aligning engagement with

autonomy and intellectual ownership (Holbrook & Rannikmäe, 2009; Kori, 2022). Colombia's *educación para la vida* frames engagement around relevance and community responsiveness, emphasizing purpose and social meaning in science learning (MEN, 1998). Taken together, these approaches suggest that curriculum designs supporting participation in disciplinary reasoning – rather than coverage alone – are more likely to sustain engagement during adolescence.

The analysis also reinforces that hands-on and project-based learning are most effective when they function as structures for disciplinary sense-making. Engagement is sustained when learning experiences support extended inquiry, evidence-based reasoning, and iterative revision of ideas over time (Blumenfeld et al., 1991; Krajcik & Blumenfeld, 2006). Such strategies allow adolescents to experience progress and competence through meaningful work, supporting both engagement and agency (Schneider et al., 2020).

A further implication concerns how science curricula position adolescents in relation to future pathways. Discussing science education primarily as pipeline preparation risks narrowing participation and reducing relevance for students who do not envisage science careers. Curricula oriented toward scientific literacy and competent participation frame science as a resource for civic reasoning, community problem-solving, and lifelong learning, in addition to occupational specialization (Feinstein et al., 2013; OECD, 2018). This perspective aligns with evidence that shows sustained engagement is a stronger predictor of long-term participation in science-related learning (Maltese & Tai, 2011; Sadler et al., 2012; Calabrese Barton et al., 2013; Mathis et al., 2023).

Teachers play a critical mediating role in translating curriculum intentions into classroom experiences. Even when curricula articulate agency-supporting goals, students' opportunities for participation depend on how teachers structure inquiry, scaffold reasoning, and provide feedback (Krajcik & Blumenfeld, 2006; Reeve, 2012). This mediation is especially consequential during adolescence, when recognition and belonging strongly shape engagement and persistence (Archer et al., 2012; Carlone & Johnson, 2007). Curriculum materials that are educative for teachers – offering guidance on inquiry facilitation, collaboration, and assessment – can help reduce reliance on individual improvisation and support more equitable participation (Gay, 2023; Ladson-Billings, 1995).

Assessment represents an additional leverage point for aligning curriculum, agency, and engagement. Performance-based assessments and formative feedback can make disciplinary reasoning visible and support iterative improvement, strengthening agency by highlighting progress rather than correctness alone (Pellegrino, 2015). In PBL contexts, such assessment practices are particularly important, as learning often unfolds through revision and reflection over time (He et al., 2023; Krajcik & Blumenfeld, 2006). Making assessment

purposes explicit helps ensure that engagement is treated as a visible dimension of learning rather than a secondary outcome (Schneider et al., 2020).

Finally, this study's document-based approach highlights both the value and limitations of analyzing intended curricula. Policy texts signal priorities and possibilities, but they cannot capture how curricula are enacted across classrooms or how adolescents experience agency and engagement in practice. Future research could extend this work through comparative studies of enacted curriculum, classroom observations, and student perspectives. Longitudinal research could further explore how agency-supporting experiences during adolescence relate to later civic participation, science-related decision-making, and diverse life trajectories, consistent with framing science education as a foundational life skill rather than a narrow pipeline (Feinstein et al., 2013; OECD, 2018; Morales-Doyle, 2018).

Conclusions

This paper examines how national science curricula in Colombia, Estonia, and the US conceptualize disciplinary learning in ways that support youth agency and engagement during adolescence. Grounded in the idea that curriculum is a social and political text, the analysis positions science curriculum as an *opportunity structure* – a set of designed conditions that can expand or constrain young people's participation, recognition, and access to scientific reasoning (Apple, 1996; Pinar, 2012). Across contexts, the central challenge is not whether adolescents can learn complex science, but whether they encounter science learning as meaningful participation and what conditions promote this participation (Osborne et al., 2003; Archer et al., 2012).

Overall, science curriculum design matters not only for what students learn, but for how they experience themselves as learners and participants in scientific sense-making beyond science careers. By focusing on universal developmental processes of adolescence while attending to contextually distinct curricular strategies, this paper contributes to international curriculum conversations centered on designing science education that is rigorous, meaningful, and broadly accessible. Future research that connects intended curriculum to enacted practice and to students' long-term civic and learning trajectories can further illuminate how opportunity structures are built, sustained, and transformed in science education.

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