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ORIGINAL PAPER

Building sustainable futures: Responsible development of AI-enabled open educational resources as digital public goods

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Abstract

This article explores the transformative potential of open educational resources (OER) as digital public goods (DPG) to foster the responsible development and use of artificial intelligence (AI). Guided by the United Nations' Common Agenda, Global Digital Compact and agenda for open solutions, along with the United Nations Educational, Scientific and Cultural Organization's Recommendation on OER, the ROAM-X framework and the FAIR principles for open science, this article promotes the importance of inclusivity, equity and global collaboration in tackling both local and global challenges. It also advocates for non-commercial, shared infrastructures that democratise knowledge and technology, ensuring they are secure, ethical and accessible to all communities. Current OER infrastructures and policy ecosystems remain fragmented and face significant challenges, as they are distributed across disconnected repositories and lack consistent metadata, limiting their reusability and accessibility. These barriers are exacerbated by inequities in internet access, and limited collaboration between institutions and nations, resulting in an uneven global OER landscape. To address these issues, the authors propose the creation of integrated and open platforms that position OER as global public goods, grounded in open principles and standards. This approach will foster resilient, collaborative, responsible and inclusive infrastructures that prioritise gender, linguistic and cultural diversity, and empower communities worldwide, thus democratising access to knowledge and enabling a more equitable technological future.

Keywords open educational resources · digital public goods · AI in education · open solutions · open education

Résumé

Construire des avenirs durables : le développement responsable de ressources éducatives libres intégrant l'IA et considérées comme des biens publics numériques – Le présent article se penche sur le potentiel transformateur des ressources éducatives

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libres (REL) envisagées comme des biens publics numériques (BPN) en vue de favoriser un développement et une utilisation responsables de l'intelligence artificielle (IA). S'appuyant sur le Programme commun des Nations Unies, le Pacte numérique mondial et le programme en faveur de solutions ouvertes des Nations Unies, ainsi que sur la Recommandation de l'Organisation des Nations Unies pour l'éducation, la science et la culture (UNESCO) sur les ressources éducatives libres, le cadre ROAM-X et les principes FAIR pour une science ouverte, l'article souligne l'importance de l'inclusivité, de l'équité et de la coopération à l'échelle mondiale pour relever les défis aussi bien locaux que mondiaux. Il plaide aussi en faveur d'infrastructures partagées, non commerciales qui démocratisent le savoir et la technologie, tout en garantissant à l'ensemble des communautés leur sécurité, leur caractère éthique et leur accessibilité. Actuellement, les infrastructures de ressources éducatives libres et les écosystèmes de politiques publiques demeurent fragmentés, et se heurtent à des difficultés majeures : leur répartition entre des dépôts numériques indépendants les uns des autres et l'absence de métadonnées cohérentes limitent la réutilisabilité et l'accessibilité des ressources. Les inégalités d'accès à Internet et la collaboration limitée entre les institutions et les États aggravent ces obstacles, ce qui contribue à creuser les inégalités dans le paysage mondial des ressources éducatives libres. Pour répondre à ces difficultés, les auteurs proposent de créer des plateformes intégrées et ouvertes, sur lesquelles les ressources éducatives libres seraient considérées comme des biens publics mondiaux, reposant sur des principes et normes ouverts. Cette approche favorisera la création d'infrastructures résilientes, collaboratives, responsables et inclusives, qui privilégieront la diversité de genre ainsi que la diversité linguistique et culturelle, et qui renforceront le pouvoir d'agir des communautés du monde entier, démocratisant ainsi l'accès au savoir et ouvrant la voie à un avenir technologique plus équitable.

Introduction

> Generative AI can be a tremendous opportunity for human development, but it can also cause harm and prejudice. It cannot be integrated into education without public engagement, and the necessary safeguards and regulations from governments (Azoulay 2023, online).

Open education as a movement, advocates for reducing the barriers to access and participation in order to extend learning opportunities to greater numbers of people, thus democratising education, access to knowledge and knowledge creation. This often involves the adoption of open educational practices (OEP), which encompass inclusive, care-centred and innovative teaching strategies and pedagogies (Cronin 2017), derived from a pedagogic ethos that promotes collaboration and transparency. This ethos aims to share effective, creative and innovative practices through open educational resources (OER), which are

> learning, teaching and research materials in any format and medium that reside in the public domain or are under copyright that have been released under an open license, that permit no-cost access, re-use, re-purpose, adaptation and redistribution by others (UNESCO 2019, p. 5).

In light of current discussions on the value of OER and the impact of artificial intelligence (AI) on education, it is crucial to reflect on the role of OER in society and its future within the context of United Nations (UN) agendas. These agendas aim to foster digital cooperation, openness and human rights, which align with the Recommendation on OER of the United Nations Educational, Scientific and Cultural Organization (UNESCO 2019) and the Dubai Declaration on OER (UNESCO 2024). Open education must remain dynamic, adapting to the changing landscape and addressing the UN's Sustainable Development Goals (SDGs) to ensure education accessibility for all. OER should specifically support UN Common Agenda Commitment 1 – leaving no one behind – and align with SDGs 4 and 10 (UNGA 2015), which focus on fostering quality education and reducing inequalities, respectively.

The 2024 UN Global Digital Compact (GDC) is defined as "a comprehensive global framework for digital cooperation and governance of artificial intelligence" that "charts a roadmap for global digital cooperation to harness the immense potential of digital technology and close digital divides" (ODET n.d., online). It was adopted at the UN Summit of the Future (UNGA 2024a) and provides a framework for the ethical and responsible use of AI in education, advocating for a human-centric approach throughout the AI lifecycle. This includes promoting accountability, transparency and robust oversight to ensure AI respects fundamental rights and fosters educational equity, particularly for vulnerable populations (UN 2024).

The GDC has a set of key components, called digital public goods (DPG), which are understood as

> building blocks for enabling countries to build safe, trusted and inclusive Digital Public Infrastructure (DPI), and are increasingly becoming critical levers for helping countries achieve the Sustainable Development Goals (UNDP 2023, p. 6).

In this context, DPI is

> a set of foundational digital systems that forms the backbone of modern societies. DPI enables secure and seamless interactions between people, businesses and governments (UNDP n.d., online).

DPG, which include open solutions such as open-source software, OER, open data and AI models (UNESCO 2024; Atenas 2026), are central to the UN's vision for an equitable digital future. The GDC promotes the creation of open-source, interoperable and ethically responsible AI solutions that support inclusive, high-quality education, particularly in underserved regions. It calls for a collaborative global infrastructure that enhances educational equity, protects data privacy and upholds the autonomy of educators and learners. The GDC reinforces the UN's

commitment to an inclusive digital ecosystem that advances sustainable development and highlights the transformative potential of openness in addressing global challenges.

In this article, we examine and reflect on the potential of OER as DPG and consider how principles of openness can shape ethical and equitable AI development. Accordingly, UN agendas advocate for open solutions that prioritise open education, open science, open data and open access (Atenas 2026). These solutions seek to build shared, non-commercial DPI that are secure, ethical and accessible to all, while democratising knowledge and technology for the benefit of local and global communities. As open solutions, they are rooted in the principles of inclusivity, equity and global collaboration, in order to solve local and global challenges.

The current OER landscape and infrastructure are fragmented and uncoordinated, with resources dispersed across disconnected platforms and often lacking reusable formats or appropriate metadata (Swain and Pathak 2024). While some nations possess well-developed OER systems, others face challenges such as unreliable internet access (Hodgkinson-Williams and Arinto 2017). Limited collaboration between institutions and countries further exacerbates the lack of a unified approach, restricting access to high-quality educational resources and hindering the potential of OER to support global learning and innovation.

Thus, developing integrated, open, interoperable and standardised platforms could help address these issues by supporting OER as DPG, fostering inclusive, transparent and collaborative development, particularly in AI, on a global scale. Open solutions could enable the creation of resilient, non-commercial DPI that support equitable access to knowledge and empower communities worldwide. Additionally, greater attention must be paid to addressing the Global North dominance of OER in English. Within this context, we argue that there is an urgent need for open, transparent and publicly governed alternatives to commercial AI platforms like ChatGPT in education. Open-source AI systems better align with the DPG principles, which include transparency, accountability and ethical oversight (DPGA n.d.) in their development, which encompasses datasets, algorithms, licensing and documentation.

In response, we recommend the adoption of frameworks such as ROAM-X and UNESCO's Internet Universality Indicators, which are

> a set of 303 indicators that aim to assess the state of Internet development at the national level according to the ROAM principles of human Rights, Openness, Accessibility, [and] Multi-stakeholder participation (Vialle 2025, p. 22, with reference to Souter and van der Spuy 2019).

The ROAM-X framework promotes openness and AI development that prioritises public benefit over profit. We also recommend adherence to the FAIR principles, which are a set of guidelines for making data "Findable, Accessible, Interoperable [and] Reusable" (Wilkinson et al. 2016, p. 2). These principles can be applied to any other type of open solution, DPG or DPI. They can also guide the creation of OER that are adaptable to local needs while maintaining global standards, promoting inclusivity, sustainability and equitable access, and supporting knowledge sharing and educational innovation on a global scale.

The following sections present the context and policy background for the article, situate OER in AI ethics and responsible frameworks, examine emerging perspectives on Generative AI (GenAI) and OER, and consider opportunities and risks in AI-enabled OER. After discussion of the issues and challenges, we then make recommendations for the responsible development of AI-enabled ecosystems as DPG. As this article refers to a large number of acronyms, Table 1 presents the key definitions used throughout.

Context and policy background

The emergence of OER stems from digitalisation, the rise of a knowledge economy driven by a connected world, and dissatisfaction with profit-driven academic publishing, leading to the creation of Creative Commons and the OpenCourseWare consortium in 2001 (UNESCO 2002; Bliss and Smith 2017). Since then, over 2 billion works have been released under open licences (CC 2019). UNESCO (2019) also advocates for a global policy roadmap that promotes equitable, inclusive education through affordable, high-quality, adaptable and inclusive learning materials (UNESCO n.d.; OER Commons 2024).

In the years following UNESCO's Recommendation on OER (UNESCO 2019), there have been significant advancements in AI technologies based on neural networks and machine learning. These AI systems, which rely on probabilistic inference and pattern recognition across large datasets, are now applied to automate tasks traditionally dependent on human labour in various fields, including data analysis, speech and language processing, image and video generation, personal interaction management, and in specialised sectors such as pharmaceutical development, fraud detection, medical screening and precision agriculture.

In education, AI is increasingly being used to support pedagogical innovation, streamline learning and content development, automate feedback and improve administrative functions, with educators exploring how AI can assist in the creation, use and discovery of OER and OEP (Fiok et al. 2022; Sharples and Pérez y Pérez 2022; Ossiannilsson et al. 2024; Wiley 2024; Tlili and Burgos 2024). When ethically addressed, this synergy between AI and OER has the potential to break down existing barriers, including accessibility and affordability, making education more inclusive and accessible for learners with disabilities and from diverse socioeconomic and geographic backgrounds.

The UNESCO Recommendation (UNESCO 2019) and the Dubai Declaration (UNESCO 2024) both highlight the role of DPG in global education, emphasising that OER, as an open solution, promotes flexible, scalable and interoperable knowledge sharing, as the democratic ethos of open education aligns with grassroots movements in open science, open source and open governance, fostering collaboration, transparency and inclusivity in policy and platform development.

However, there are also significant concerns about the datafication of education (Beetham et al. 2022; Atenas et al. 2020), including the devaluation of academic work, alteration of pedagogical relationships, reinforcement of biases in AI training datasets and risk of systemic discrimination against marginalised groups. Moreover,

Table 1 Key terms used in this article

Acronym	Term	Definition	Example
DPG	Digital public goods	Open-source digital solutions that help countries build inclusive and secure digital public infrastructure (DPI)	Open-source AI models, OER platforms, open datasets
DPI	Digital public infrastructure	Foundational digital systems that enable secure digital interactions between people, businesses and governments	National open-access learning platforms, digital ID systems
FAIR	FAIR principles	Guidelines for making data and open resources findable, accessible, interoperable and reusable	Open repositories ensuring OER materials are easy to locate and modify
GDC	Global Digital Compact	A global framework for digital cooperation and governance, ensuring ethical AI use and digital equity	Policies ensuring AI development respects human rights and supports education
OE	Open education	A movement to reduce barriers to education and increase accessibility through open knowledge sharing	Use of OER to provide free learning resources to underserved communities
OEP	Open educational practices	Pedagogical approaches that promote collaboration, transparency and innovation in education through open resources	Teachers co-developing OER-based curricula with students and educators worldwide
OER	Open educational resources	Teaching, learning and research materials available under an open licence, allowing free access, reuse and adaptation	Openly licensed learning and teaching resources, open-access textbooks, lesson plans, massive open online courses (MOOCs)
OS	Open solutions	A set of principles that promote inclusivity, equity and global collaboration through open knowledge-sharing infrastructure	Open science, open data, open access, open education
ROAM-X	Internet Universality Indicators	A framework and associated indicator set for assessing internet development based on rights, openness, accessibility, multi-stakeholder participation and cross-cutting issues	Countries evaluating AI and internet governance policies under UNESCO standards
SDGs	Sustainable Development Goals	A set of 17 global goals established by the UN to address issues like poverty, education and equality	SDG 4 (Quality education) and SDG 10 (Reduced inequalities)

the lack of access to necessary infrastructure for many educators and learners could exacerbate existing inequities in education.

The ethical deployment of AI requires adherence to ethical design principles, ensuring fairness, equity, transparency and protection of learners' privacy (Farrow 2023). Bias audits and auditable open-source algorithms (Galdon Clavell et al. 2020; Vecchione et al. 2021; Atenas and Caldwell 2026) can enhance accountability, but these must also align with pedagogical priorities. Additionally, sustainable practices, such as green computing solutions, should be prioritised to reduce AI's environmental impact (Murugesan 2008; Crawford 2021; Valdivia 2025). While a 2012 resolution by the Human Rights Council established that human rights are equally applicable online and offline (HRC 2012, p. 2, item 1), the recent *Report of the Special Rapporteur on the Right to Education* (UNGA 2024b) emphasised that AI should advance the right to education. This approach advocates for the adoption of human rights-based principles, including inclusive decision-making, non-discrimination, risk accountability, access to information and robust privacy protections.

International guidelines, such as the AI recommendations of the Organisation for Economic Co-operation and Development (OECD 2024) and the European Commission's *Ethics Guidelines for Trustworthy AI* (AI HLEG 2019), highlight the importance of multi-stakeholder involvement in AI governance. The Council of Europe's 2024 Framework Convention on AI (CoE 2024).and UNESCO's report on *AI and Democracy* (Innerarity 2024) advocate for public discussions and the development of AI-related competencies, ensuring informed participation in societal decision-making. The UN's Department of Global Communications promotes open solutions for an equitable digital future, encouraging collaborative efforts to build inclusive and secure digital environments. This approach is reflected in a series of high-level declarations, recommendations and guidelines that frame and present practices, aspirations and policy development for the open movements that directly or indirectly relate to open education (see Figure 1).

These declarations, recommendations and guidelines aim to create a more open and equitable educational landscape by promoting and raising awareness of open practices. These frameworks encourage transparency, collaboration and reproducibility in research, while advocating for policies that support capacity building,

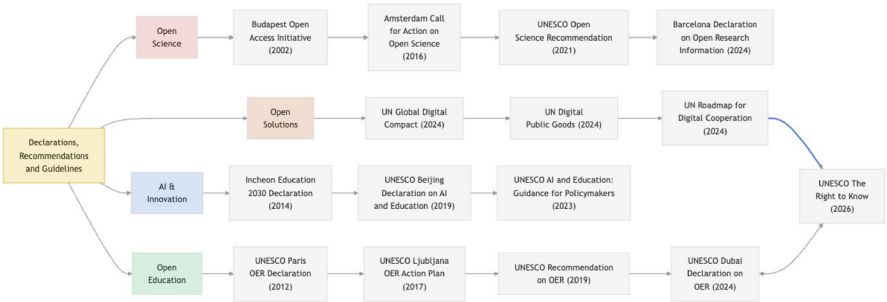


Figure 1 Frameworks of open practices and solutions. *Source:* Flowchart created using open-source Mermaid syntax and code-edited using authors' own github

open education and the ethical use of AI to ensure equitable benefits and respect for human rights. However, concerns about the impact of AI remain, such as reducing critical thinking, undermining academic freedom and increasing privacy risks, particularly for children. Addressing these challenges requires a responsible approach to AI that emphasises ethical practices, transparency, informed consent and support for educators in understanding AI systems.

The role of AI in intellectual property presents ethical and legal challenges due to the lack of established case law, leaving key questions unanswered. In the United States, rulings suggest that AI-generated content cannot be copyrighted, as copyright law assumes human authorship, meaning such content falls into the public domain (Caldwell 2023). This lack of ownership protection creates difficulties for educators and creators using AI to develop OER. For example, GenAI – which Stefan Feuerriegel et al. define as "computational techniques that are capable of generating seemingly new, meaningful content such as text, images, or audio from training data" (Feuerriegel et al. 2024, p. 111) – often uses copyrighted materials to produce new content, thus bypassing copyright protections. This raises significant ethical concerns about intellectual property, as it could redefine authorship, ownership and originality in the context of AI-assisted creation.

Ensuring that OER are developed with inclusivity and equity in mind will foster a digital education landscape where high-quality OER (Tlili et al. 2023; Hilton 2020) are accessible to all learners, regardless of geographic, socioeconomic or cultural background. This vision aligns with the UN's open solutions agenda, positioning OER as part of a broader ecosystem where knowledge is a shared public good, enhancing collective empowerment and sustainable development. This approach promotes universal access to adaptable education, improving equity across various socioeconomic contexts and encouraging the development of OER platforms as DPG.

However, balancing the potential benefits and risks of AI is critical. As mentioned above, AI poses challenges to existing copyright and intellectual property laws, which are struggling to adapt to its generative nature. Training AI on copyrighted materials raises concerns about violations, as it involves duplication, storage and processing of these works (Appel et al. 2023). AI providers often assert that their outputs are original and do not infringe copyright, although ongoing legal cases, such as The New York Times vs. OpenAI, may shape how intellectual property rights evolve with generative technologies (Pope 2024).

Despite the challenges and risks of exacerbating inequalities, AI integration continues to expand (Park and Humphrey 2019; Bender et al. 2025). AI-enabled OER can be customised to diverse learner needs, e.g. by facilitating the creation and adaptation of multimedia content, or by making content more accessible. The synergy between OER and AI can offer significant opportunities for innovation and efficiency in education. However, as AI becomes increasingly integrated into existing educational tools, its ubiquity seems inevitable, prompting many educators to explore its potential to enhance their work. At this stage, ethical considerations, are critical to protect both learners and educators from potential harm.

As legal frameworks evolve in response to AI, albeit slower that the technology itself, ethical discussions around its deployment are intensifying. The development

of AI-enabled OER must prioritise addressing bias and discrimination to avoid reinforcing societal inequalities. Ethical design principles should guide resource development, focusing on data justice and ethics to protect learners' privacy and prevent misuse of personal information. Conducting bias audits can improve the fairness and transparency of datasets and algorithms, while open-source algorithms ensure scrutiny, though privacy and pedagogical focus must be maintained (Farrow 2023).

Additionally, AI-enabled OER must incorporate sustainable practices, such as green computing, to reduce environmental impacts (Murugesan 2008; Crawford 2021). To navigate the future effectively, it is vital to foster critical data and AI literacies among educational stakeholders (Atenas et al. 2020; Atenas et al. 2023). Data-driven technologies and OEP can enhance participation and promote collaborative approaches, but they must prioritise data protection, transparency and accountability for the democratic dissemination of knowledge. As such, critical data and AI literacies should be central to strategic guidance in open education, supporting collaboration, creativity and equitable knowledge sharing.

Situating OER in AI ethics and responsible frameworks

To advance the responsible development of AI-enabled OER, ethical considerations in AI use in education must be prioritised, alongside policies that align with equity, inclusion and transparency. David Leslie defines trustworthy AI as a

> set of values, principles, and techniques that employ widely accepted standards of right and wrong to guide moral conduct in the development and use of AI technologies (Leslie 2019, p. 3).

The development of AI-enabled OER should also embrace data justice principles, promoting equitable and ethical data use. Key pillars of data justice – visibility, engagement with technology, and non-discrimination – enhance responsible AI practices by ensuring transparency and fairness in data collection, analysis and application (Taylor 2017; Dencik and Sanchez-Monedero 2022). The development of AI-enabled OER can contribute to a more just, inclusive and ethical educational environment by aligning with the pillars of data justice. Visibility reinforces the importance of diverse representation, ensuring that all voices are valued in education, and underscores the need for institutions to protect individuals' data, building trust among learners and educators. Engagement with technology highlights the need for equitable access to data and technology, empowering stakeholders to make informed decisions and ensuring that the benefits of AI are accessible to all, regardless of background. Non-discrimination focuses on identifying and challenging biases and countering unfair practices in data use and analysis. By prioritising these pillars, AI-enabled OER practices and policies can be advanced, as illustrated in Figure 2.

When developed with human oversight and secure systems, AI-enabled OER can foster greater trust among learners and educators, ensuring that their educational data are protected while benefiting from AI-enhanced, contextually relevant learning. Adopting responsible AI principles alongside the ROAM-X framework

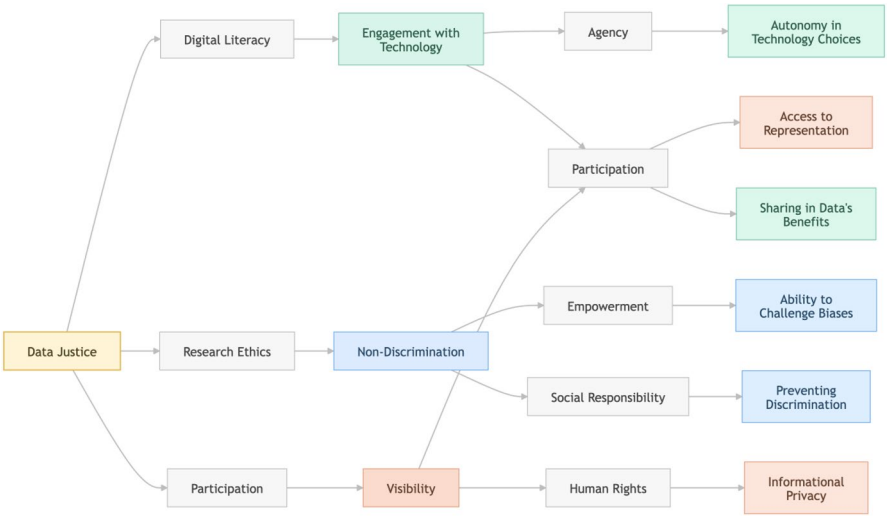


Figure 2 Data justice pillars. *Source:* Flowchart created using open-source Mermaid syntax and code-edited using authors' own github

and indicators (UNESCO 2022) ensures equitable access to high-quality OER. For example, the AI4People framework (Floridi et al. 2016) enhances practice in education by ensuring that AI systems respect human agency, maintain technical robustness and safety, and prioritise privacy and data governance, as outlined in the European Commission's *Ethics Guidelines for Trustworthy AI* (AI HLEG 2019).

AI-enabled OER should address the needs of diverse and vulnerable groups by offering culturally responsive educational content that reduces learning inequities. UNESCO's *Recommendation on the Ethics of AI* (UNESCO 2022) highlights the importance of transparency and explainability, which are essential for building trust in AI-enabled OER. It stresses privacy and data protection, offering guidelines to safeguard learners' digital rights, ensuring that OER remains secure and resilient. It also supports the development of inclusive and culturally responsive OER, prioritising the needs of underrepresented groups while safeguarding learners' digital rights. In alignment with this, the Global Initiative of the Institute of Electrical and Electronics Engineers (IEEE 2019), the AI Principles developed during the 2017 Conference on Signals, Systems, and Computers held at the Asilomar Conference Grounds in California (FLI 2017) and the Montréal Declaration for a Responsible Development of AI (UdeM et al. 2018) advocate for the wellbeing of all stakeholders, promoting fairness, transparency and accountability in AI systems. The principles listed in responsible AI guidelines that should be integrated in OEP are illustrated in Figure 3.

These principles align with the ROAM-X framework's goals of multi-stakeholder participation and sustainable development, ensuring that AI in OER is designed for long-term safety and aligned with human values. By prioritising fairness, equity and justice within AI systems, these guidelines aim to avoid harm, distribute benefits equitably and foster societal wellbeing. The responsible

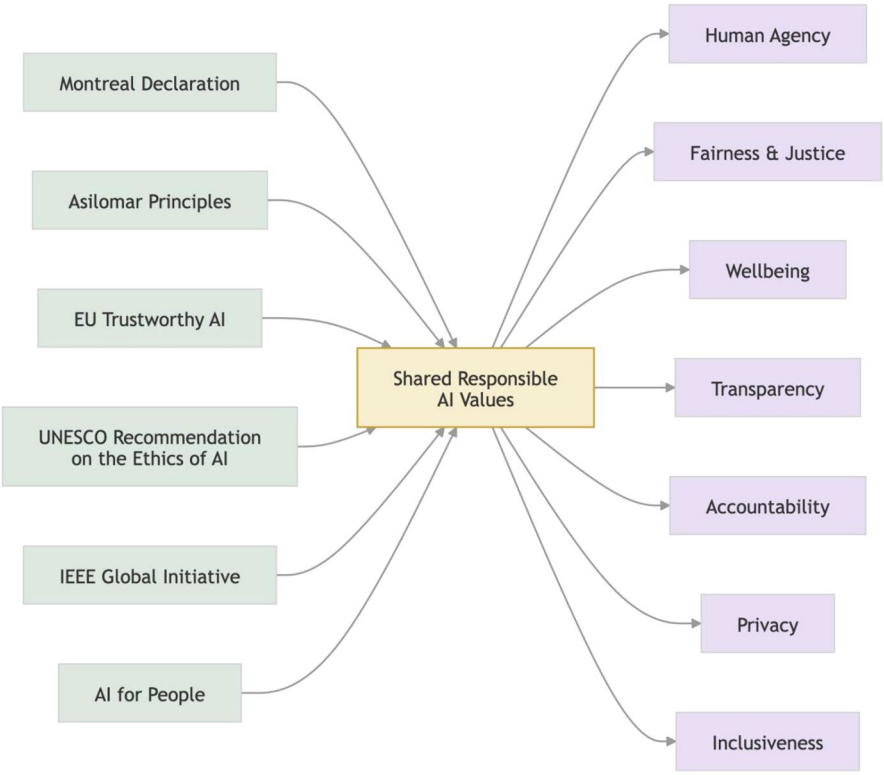


Figure 3 Responsible AI guidelines and shared core values. *Source:* Flowchart created using open-source Mermaid syntax and code-edited using authors' own github

integration of AI in OER not only improves educational accessibility but also contributes to social justice goals, advancing environmental sustainability and reducing biases (Weidinger et al. 2023).

Open education, which is inherently committed to social justice and equity, requires ongoing critical reflection on how data may perpetuate systemic inequalities. Educators should be encouraged to align their work with ethical AI frameworks, focusing on privacy, data protection and digital citizenship, while also challenging underlying assumptions and identifying biases. The value of these frameworks lies in ensuring trustworthy AI systems by addressing technical robustness and data protection, thereby helping to keep AI-driven education safe and reliable. In addition, these frameworks foster capacity building and international cooperation to support the responsible use of AI in developing culturally responsive OER, mitigating racial and gender biases and ensuring equity, accessibility and quality education for all learners.

Emerging perspectives on GenAI and OER

The current landscape of AI in open education is still developing, with ongoing efforts to foster meaningful dialogue and progress. While some critics argue that discussions around AI and openness are still in their infancy, others contend that the surge of GenAI in education is generating inflated expectations without significant advancements in integrating AI with open education principles. Despite the growing integration of GenAI in education, which is transforming how learning materials are produced and engaged with, substantial innovations that effectively align AI with open education remain elusive.

Reliance on GenAI requires open education practitioners to adopt responsible and ethical frameworks to ensure that AI-enabled OER are sustainable, equitable and accessible. OER must address challenges arising from GenAI use, such as cultural sensitivity, environmental sustainability, accessibility and inclusivity. This involves developing OER that are culturally responsive, promote digital literacy and uphold the DPG principles. The GDC (UNGA 2024a) and UNESCO Recommendation (UNESCO 2019) support this vision, advocating for the responsible integration of emerging technologies, including AI, to make high-quality education accessible to learners worldwide. Achieving this goal requires building capacity and sustainable models that can adapt to evolving technologies and pedagogies.

Protecting intellectual property rights while ensuring open access is essential for enabling educational materials to be shared and reused in compliance with copyright law. To sustain OER, comprehensive strategies are needed to safeguard data privacy and security, especially with regard to concerns about the misuse of GenAI. This includes addressing racial and gender biases in GenAI content and adopting strategies to mitigate these biases in the development and distribution of OER.

The ROAM-X framework – which focuses on rights, openness, accessibility, multi-stakeholder participation and cross-cutting issues – provides a guide for educators in the responsible development of AI-enabled OER. By prioritising digital rights protection and equitable access to educational materials, this framework ensures that AI-generated OER are inclusive and uphold values of openness and collaboration. The emphasis on multi-stakeholder participation promotes contributions from diverse educators, learners and communities, enhancing cultural sensitivity. Additionally, ROAM-X addresses critical issues such as bias mitigation and ethical data practices, ensuring the creation of sustainable and equitable resources across different socioeconomic contexts. Thus, embedding ROAM-X principles in the development of GenAI-enabled OER can effectively foster openness, inclusivity and sustainability in a digital learning environment that supports social justice and the democratisation of knowledge, as reflected in Table 2.

The ROAM-X framework promotes the creation of OER that are accessible to all, regardless of geographic or socioeconomic barriers, while encouraging multi-stakeholder participation in developing culturally responsive and

Table 2 ROAM-X principles and OER best practice examples

ROAM-X principle	Best practice example
Rights	Ensure protection of intellectual property and privacy rights in GenAI-enabled OER development. Uphold learners' and creators' digital rights to freely access, modify and distribute OER.
Openness	Use openly licensed materials and share GenAI-enabled OER under open licences to encourage reuse and remixing. Foster transparency in AI-generated content by clearly indicating AI involvement.
Accessibility	Design OER with accessibility in mind, including compatibility with assistive technologies and consideration of diverse learning needs. Ensure easy access to OER across multiple devices and regions.
Multi-stakeholder participation	Involve a wide range of stakeholders, including educators, learners, technologists and policymakers, in the creation and use of GenAI-enabled OER. Encourage collaboration across sectors for feedback and improvement.
Cross-cutting issues	Integrate gender-sensitive content in OER to ensure inclusivity and avoid gender biases in AI-generated content and data used for OER development. Protect children's data when creating GenAI-enabled OER. Promote sustainability education and environmental awareness. Use AI tools that are energy-efficient and aligned with sustainable digital practices.

context-appropriate content. It also focuses on gender equality, addressing biases in AI-generated content and ensuring that OER creation aligns with sustainable development and ethical standards. However, these principles should also be accompanied by technical standards to ensure robust and sustainable OER infrastructures.

The FAIR principles from open science can play a critical role in ensuring that OER are accessible globally, making educational content easier to find, access and reuse, and preventing digital knowledge from becoming siloed. These principles (data should be findable, accessible, interoperable and reusable) also promote inclusivity and contribute to collective knowledge advancement. Interoperability ensures that AI-driven OER platforms can seamlessly integrate with other systems, allowing for greater flexibility and enabling adaptation to local contexts and languages. AI can also personalise learning, but without adherence to the FAIR principles the content may not be easily discoverable or reusable, thus limiting its potential.

OER and AI-enabled OER, developed as DPG using the FAIR principles, go beyond content delivery by fostering collaboration and innovation. Best practice examples include providing clear licensing metadata, ensuring compatibility across formats and promoting transparency in content generation and adaptation. These approaches foster a resilient, user-driven ecosystem for OER, supporting the evolution of educational resources that meet diverse needs across different contexts, as shown in Table 3.

Table 3 FAIR principles and OER best practice examples

FAIR principle	Technical guidance	Best practice example
Findable	Use standardised metadata and persistent identifiers for all OER. Optimise for search engine discoverability.	Assign DOIs to each OER material. Use comprehensive metadata to ensure easy searchability.
Accessible	Ensure content is available in open, accessible formats (e.g. PDF, HTML, ODT). Host content on open-access platforms and repositories.	Publish OER on platforms like OpenStax and OER Commons. Ensure compatibility with assistive technologies like screen readers.
Interoperable	Use open standards (e.g. SCORM, IMS) and APIs to facilitate integration across platforms. Employ standardised data formats.	Use IMS Global Standards to create educational content that can be integrated with different learning management systems.
Reusable	Provide clear open licences and detailed documentation on how content can be modified. Ensure modular content design for easy adaptation.	Use Creative Commons Attribution (CC BY) licences to allow adaptation and reuse. Structure OER content in modular formats for easy customisation and remixing.

Note. DOI = digital object identifier; PDF = portable document format; HTML = hypertext markup language; ODT = open document text; SCORM = sharable content object reference model; API = application programming interface.

Opportunities and risks in AI-enabled OER

AI offers a myriad of opportunities for educators to enhance OER adoption, aligning with the DPG principles and the ROAM-X framework. GenAI can help educators create diverse educational content, improving accessibility for all learners, including those with disabilities. Features like text-to-speech and content adaptation ensure inclusivity, catering to the unique needs of each student, with a focus on equity, access and lifelong learning. AI integration streamlines the often time-consuming process of resource production, automating the creation of educational tools such as quizzes, rubrics and case studies. This reduces production costs and time, allowing educators to focus more on facilitating learning and providing targeted support. AI's scalability also enables adaptive learning pathways, adjusting the complexity of activities based on individual student progress.

From a DPG perspective, AI-enabled OER can facilitate the translation of content into multiple languages, making education more accessible globally. However, it is crucial that these resources are culturally and contextually appropriate. AI can also help keep materials updated with the latest research and information. Thus, great care is required to ensure that automated processes do not inadvertently introduce or multiply unhelpful or unethical biases.

AI presents several risks to open education, particularly to its core principles of accessibility and equity. One key concern is the potential for market capture by venture capital, which could centralise educational resources in the hands of a few tech corporations. This oligarchic control threatens the democratising potential of open education by prioritising private profit, thus limiting the availability of diverse and inclusive resources. Initiatives such as developing large language models (LLMs) for low-resource languages (e.g. Finnish and Basque), may mitigate this risk (Prevete 2024). However, the openness and democratic nature of such initiatives remain uncertain.

GenAI models also blur the lines of consent and attribution, with many corporate AI systems being developed without adequate attention to copyright. This raises ethical concerns around informed consent and appropriate attribution and risks undermining the foundational openness of the commons. Moreover, the significant computational and energy demands of GenAI models pose environmental sustainability concerns due to increased carbon emissions.

The consequences of these risks are profound. Without coordinated efforts to address them, existing educational inequalities could be exacerbated. While GenAI has considerable potential, it could flood the OER landscape with vast amounts of incorrect, biased or misleading content, reinforcing entrenched biases and neoliberal narratives embedded in AI algorithms. This may lead to AI-generated OER content failing to meet established quality standards, leading to increased mistrust among potential users.

GenAI tends to excel in well-documented areas, often leaving niche or less popular topics underrepresented – a pattern similar to that observed in Wikipedia content. This disparity could lead to AI models replicating training data verbatim, potentially infringing on copyright. Furthermore, corporate AI models

often fail to adequately address copyright concerns, and there is an added risk of AI-generated content "hallucinating" sources or citations, which typically serve as a marker of quality. Designing AI-enabled OER requires careful consideration of interrelated risks that impact both development processes and learner experiences.

Responsible data use is central, as AI initiatives rely heavily on the collection and analysis of user data. Adherence to principles of informed consent and transparency is essential to avoid biases in predictive models and prevent issues like discrimination by proxy. Moreover, platforms claiming to offer "open" or "free" AI-enabled resources may actually operate on a quid-pro-quo model, where user data become the currency, compromising user privacy and autonomy. Educators and institutions must implement robust data protection measures informed by a data justice perspective to ensure that AI-enabled OER respect data sovereignty. Tahu Kukutai and John Taylor describe data sovereignty as a "way to include the notion of the supremacy of systems of data collection and use" (Kukutai and Taylor 2016, p. 57) – particularly for indigenous and marginalised communities – thus empowering users with meaningful choices about how they participate in data collection.

As ethical considerations of data use unfold, algorithmic fairness and data security become critical for developing equitable AI-enabled OER. Future initiatives should enable educators and learners to assess and audit AI models for biases and discriminatory practices, while implementing stringent security measures to protect sensitive data. Since AI systems inherit biases from their training data, continuous auditing is necessary to prevent the exacerbation of inequalities based on gender, race or socioeconomic status, and to avoid creating new divides. Additionally, unequal access to reliable internet and technology can marginalise disadvantaged learners, while an over-reliance on AI-generated resources risks diminishing the value of human creativity and judgement in education.

In this context, personalised guidance, empathy and contextual understanding, vital for effective teaching, could be compromised, leading to learner disengagement and poorer educational outcomes. The use of AI in education must remain inclusive, which may ultimately only be realised through forms of AI data sovereignty and agency. These concepts relate to the ability to influence various aspects of AI, including its creation, operation, destruction and overall dynamics (e.g. behaviour, development and interactions). Such control can vary and, crucially, can be both pooled and transferred. Individual agency, however, is "deeply connected to the distribution of knowledge and power" (Baack 2015, p. 1). In this context, much like data sovereignty, individual agency can be understood as self-ownership, particularly in relation to one's own body, choices and data.

Discussion

Social justice and equity are foundational to OER as DPG, but there are significant ethical, legal and educational concerns regarding the use of GenAI. Over-reliance on AI tools, such as writing-assistance platforms, may undermine critical thinking and creativity, raising questions about how technology affects learning

at scale. Additionally, biased AI outputs can perpetuate structural inequalities, emphasising the need for fairness and inclusivity in AI integration. The legal ambiguity surrounding AI-generated content also challenges intellectual property laws, requiring educators to balance innovation with ethical content creation.

Further concerns include the impact of AI on public knowledge infrastructures and the fragmentation of OER systems. This highlights the need for cohesive, secure and ethically sound digital infrastructures that align with the SDGs – particularly SDG 4 on quality education (Pimenta Arruda and Pimenta Arruda 2024). The reliance on commercial AI platforms like ChatGPT underscores the need for publicly governed AI systems that adhere to ethical practices. The dependence on potentially unreliable data further calls for robust governance frameworks. Establishing transparent, ethical and accountable AI systems is essential to fostering trust, collaboration and global accessibility of high-quality educational resources in line with the ROAM-X framework.

In addition to broader concerns, integrating traditional and indigenous knowledge within open licensing frameworks presents specific challenges. The UN's recognition of indigenous rights and cultural preservation can guide the creation of a more responsible ecosystem for OER. Current systems often fail to address cultural restrictions around traditional knowledge, leading to insufficient protections and limited access in open educational contexts like Creative Commons. Advocating for culturally sensitive licensing that respects these restrictions while enabling controlled access is crucial to ensure inclusivity and representation. (Note that licences supporting "traditional knowledge" are still under development.)

Promoting AI literacy and critical thinking skills is vital for fostering a just educational environment and engaging critically with AI-generated content. Clear guidelines on copyright and AI, particularly in the licensing of AI-generated OER, are essential to define the legal status of educational materials created using AI. By supporting initiatives that align with the UN's goals for open solutions and for DPG, educators and institutions can contribute to a more interconnected and globally accessible educational infrastructure.

To effectively harness the potential of OER as DPG, there is an urgent need to revise and update OER policies and platforms in alignment with the UN's agendas and the UNESCO (2019) Recommendation. This includes integrating the ROAM-X framework for OER development and adhering to the FAIR principles for OER indexing, to ensure that OER are not only accessible and retrievable but also designed to promote equitable access and inclusion across diverse populations. Additionally, improving current fragmented governance models is essential for establishing international, gender-sensitive and multi-stakeholder appropriate spaces for participation in policymaking and governance. By fostering collaborative frameworks that involve a range of stakeholders – including educators, policymakers and representatives from marginalised communities – we can create a robust ecosystem for OER that reflects collective values and priorities. This approach will not only enhance the quality and relevance of OER but also advance global educational equity, ensuring that all learners benefit from high-quality, culturally responsive educational materials.

Recommendations for responsible AI-enabled OER ecosystems

To advance the responsible development of AI-enabled OER as DPG, we advocate for a multi-layered approach that integrates supportive policies, ethical considerations and global frameworks aimed at promoting equitable and accessible education. This would align with the UNESCO Recommendation (UNESCO 2019) by establishing regulatory frameworks that encourage open licensing of publicly funded educational and research materials. This will ensure that OER can be created, adapted and redistributed, fostering high-quality and inclusive education for all, while facilitating the development of AI-enabled OER as DPG. It will also create and nurture ecosystems that enable cross-border knowledge exchange while prioritising ethical principles and sustainable practices.

Both the UNESCO Recommendation (UNESCO 2019) and the Dubai Declaration (UNESCO 2024) stress the need for open-licensed, interoperable platforms that support OER creation and reuse, incorporating AI features such as translation and resource adaptation. In future, the ethical use of AI in education must prioritise privacy, fairness and bias prevention. GenAI tools employed for OER creation must operate transparently, ensuring users retain control over their data and upholding ethical standards around data sovereignty, agency and informed consent. Policies on data collection and usage must ensure platforms adhere to these ethical practices.

Intellectual property rights are essential in the development of AI-enabled OER, as AI tools raise questions about authorship, attribution and copyright. Comprehensive intellectual property policies are needed to address these issues, supporting ethical remixing while preserving authorship rights. These policies must also promote algorithmic fairness, mitigate bias and equip educators and learners to critically assess AI models, preventing the reinforcement of inequalities. To align with the DPG principles and contribute to SDG 4 on quality education, OER platforms must adhere to global standards for privacy, security and inclusivity. Enhanced global collaboration will strengthen OER infrastructure and support equitable education for all.

While technical models aligned with the FAIR and open principles are emerging (e.g. White et al. 2024; Gibney 2024; Liesenfeld and Dingemanse 2024), standards for technology and intellectual property in open education remain underdeveloped. When framed as DPG, OER platforms should adopt the FAIR principles, standards and formats to ensure interoperability, facilitate integration across educational systems and foster a global knowledge commons. This can empower educators and learners worldwide and make education more flexible, sustainable and responsive to local and global needs. However, the commons can also extend beyond content to potentially incorporate AI tools and infrastructure that support equitable access.

At this critical juncture, policy can serve as an effective driver towards achieving these goals as practice evolves. To effectively shape AI policy in open education, which is still in its formative stages but gaining urgency, strategic guidance should include the following elements:

- *Promote responsible use of AI:* Encourage ethical AI use in OER with principles like fairness, transparency and privacy protection.
- *Provide ethical guidelines:* Develop comprehensive guidelines for integrating AI into OER creation, ensuring inclusivity and high-quality resources.
- *Support research:* Fund research on the impact of AI in open education to inform policy and practice.

Key policy considerations include:

- *Capacity building:* Integrate AI competency frameworks at all educational levels, ensuring universal internet access and ethical AI design.
- *Informed consent:* Ensure platforms collecting data for AI-enabled OER have informed consent mechanisms and institutional auditing of learner data.
- *Transparency:* AI-enabled OER platforms must disclose when content is AI-generated and explain the systems behind it.
- *Brokering:* Communicate with stakeholders in clear language and offer avenues for dialogue and clarification.
- *Auditing:* AI-enabled OER should undergo independent academic review to ensure reliability and fairness (Dwivedi et al. 2023).
- *Equity:* Ensure AI-enhanced education does not exacerbate inequalities, guaranteeing access for all learners.

The Dubai Declaration (UNESCO 2024) provides guidelines for practice and policy on OER as DPG, to foster equitable access to knowledge, address intellectual property rights and foster international cooperation. The Declaration highlights key insights for practice and policy in terms of capacity building for digital literacy and responsible technology use, as well as intellectual property rights and sustainable licensing. It also promotes the improvement of governance models in terms of international collaboration and gender parity to ensure sustainability frameworks and promote green technology, as summarised in Table 4.

Finally, in alignment with UNESCO's broader objectives, the responsible use of AI in OER should prioritise inclusivity, sustainability and learner wellbeing. While AI in OER offers opportunities to expand educational reach, it also risks deepening the digital divide and increasing dependency on large tech platforms. By embedding openness, fairness and human-centred AI principles into OER initiatives, educators and policymakers can ensure AI promotes equitable access to quality education. Conversely, inaction or poor decisions will limit equitable access. Our proposed framework, presented in Table 5, highlights key categories for policymaking to help institutions develop an ethical and responsible landscape for AI-enabled OER.

OER as DPG have the potential to significantly improve people's lives. As the landscape of open education and AI-enabled OER evolves, we must reaffirm our commitment to equity, inclusivity and ethical practices. The responsible development of AI-enhanced OER must be guided by policies that align with international frameworks like the SDGs, ROAM-X framework and FAIR principles for data management. It is essential that educational resources remain accessible, retrievable and developed through collaboration. Ultimately, we must create an ecosystem that

Table 4 Summary of the Dubai Declaration on OER

Area	Practice recommendation	Policy recommendation
Capacity building	Train stakeholders in the responsible use of GenAI for OER.	Develop guidelines to prioritise responsible AI use and open licensing.
	Promote digital literacy to evaluate and use emerging technologies effectively.	
Accessibility	Use AI for OER translation, text-to-speech tools and other assistive technologies.	Support low-bandwidth, inclusive and equitable access for vulnerable populations.
	Ensure metadata integrity and compliance with privacy standards.	
Intellectual property	Embed licensing details in AI-generated outputs.	Advocate for policies that ensure attribution and protection of authorship in AI models and OER.
	Enhance awareness of copyright exceptions and limitations for OER creators.	Support the integration of machine-readable licences in metadata for AI models and OER.
Sustainability	Foster green computing and energy-efficient development of DPG.	Implement participatory governance frameworks for OER ecosystems.
	Build interoperable open-source platforms for OER curation and management.	
International cooperation	Strengthen global and regional networks for collaborative OER initiatives.	Establish frameworks for engaging with legal experts and open communities on licensing and intellectual property issues.
	Facilitate community-driven AI projects aligned with the UNESCO 2019 Recommendation on OER.	

Table 5 Ethical and responsible framework for AI-enabled OER initiatives

Element	Objective	Key components
Skills development	Equip educators, content creators and AI developers with skills for ethical AI-enabled OER creation.	*Capacity building*: Develop training on AI, ethics and OER creation. *Digital literacy*: Promote responsible AI use. *AI literacy*: Develop AI expertise in education.
Privacy safeguarding	Protect learners' and educators' data and privacy in AI-enabled OER.	*Data protection policies*: Comply with regulations (e.g. the European Union's General Data Protection Regulation). *Privacy by design*: Integrate privacy from the start. *Data transparency*: Communicate data usage practices.
Collaboration promotion	Encourage collaboration in AI-enabled OER creation, sharing and improvement.	*Collaborative platforms*: Develop platforms for AI-OER collaboration. *Interdisciplinary teams*: Foster collaboration among educators, AI experts and creators.
Ethical AI integration	Ensure AI in OER aligns with ethical principles and enhances quality education.	*Ethical AI guidelines* Develop responsible guidelines for AI use. *Bias mitigation*: Address AI biases in OER. *User empowerment*: Support informed decisions by educators and learners.
Evaluation and continuous improvement	Continuously assess and improve AI-enabled OER.	*Impact assessment*: Evaluate the impact of AI on education and privacy. *Feedback mechanisms*: Collect feedback from users. *Iterative development*: Improve OER based on assessments.
Ethical AI-OER policy framework	Create a policy framework for the ethical use of AI in OER.	*Regulatory compliance*: Align with data protection and education standards. *Ethical guidelines* Promote responsible AI use in OER. *Monitoring and enforcement*: Ensure policy compliance.

democratises knowledge access, empowers diverse communities and fosters dialogue to build a just and innovative educational landscape.

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