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Embedding UN SDGs in chemistry education through project-based learning: insights from case studies in the UK and USA

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Chemistry education is central to achieving the United Nations Sustainable Development Goals (UN SDGs) by advancing resource efficiency, reducing environmental impact, and embedding sustainable practices. This study reports two international case studies at the University of the West of Scotland (UK) and Wentworth Institute of Technology (USA), which integrate UN SDGs into undergraduate curricula through project-based learning. Students engaged in projects linking foundational chemistry concepts to real-world sustainability challenges. Assessment combined written reports, presentations, and reflective tasks to evaluate disciplinary knowledge and transferable skills. Results indicate that UN SDG-aligned projects enhance engagement, deepen understanding of sustainability, and foster interdisciplinary competencies essential for addressing global challenges. This work provides a practical framework for embedding sustainability into STEM education through active learning approaches.

Sustainability spotlight

This work demonstrates how chemistry education can advance the United Nations Sustainable Development Goals (UN SDGs) through project-based learning in two distinct institutional contexts. At the University of the West of Scotland, students collaborated on global sustainability challenges, such as renewable energy, water security, and resource stewardship, while applying core chemistry concepts and creative approaches. At Wentworth Institute of Technology, students individually analyzed campus sustainability practices and proposed actionable strategies aligned with selected UN SDGs. Both projects fostered critical thinking, innovation, scientific communication, and meta-skills essential for addressing complex environmental issues. By explicitly linking chemistry topics to real-world sustainability outcomes, this study offers an adaptable framework for embedding UN SDG-driven challenges into STEM curricula. While UN SDG 4 (Quality Education) and UN SDG 13 (Climate Action) are central, many other goals including UN SDG 3 (Good Health and Well-being), UN SDG 6 (Clean Water and Sanitation), UN SDG 7 (Affordable and Clean Energy), UN SDG 9 (Industry, Innovation and Infrastructure), UN SDG 12 (Responsible Consumption and Production), and others are integrated throughout the projects.

Introduction

Chemistry and the UNSDGs

In 2015, the United Nations launched the 2030 United Nations Sustainable Development Goals (UN SDGs),[1] aimed at improving livelihoods and achieving a sustainable future for everyone. The UNSDGs comprise 17 fundamental and interconnected goals to bring global change.[1] From the 17 UN SDGs, several are directly related to the chemical sciences, particularly those involving health, clean water, energy, responsible production, and climate action, while many others are indirectly supported or interconnected through the contributions of chemistry to technology, materials, and environmental management. To enforce sustainable practices, countries, governments, industries, and organizations worldwide must apply the UN SDG guidelines within their operational, educational, and developmental activities.

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Chemistry largely shapes our world and is central to human existence as an impactful branch of science. Chemistry is central to other sciences, such as biochemistry, environmental science, geochemistry, pharmacology, polymer science, medicinal chemistry, molecular biology, nanoscience, oil and petroleum, and others. In our world's industries, chemistry is directly connected to the UN SDGs, for instance: materials and manufacturing (goals 3, 6 and 9 to 13), energy (goals 7, 11 and 13), food and agriculture (goals 1, 2, 7, 9 and 13), health (goals 3, 4, and 8),[2] and technology (goals 8 and 10–17) (Fig. 1 and 2).

Chemical sciences advocate for global sustainability in solving pressing environmental and climate change problems. For chemistry to be an important tool towards driving global sustainability, the real-world applications of chemistry need to be taught in classrooms to shape aspiring and future scientists who will lead the efforts of sustainability.[3,4]

Embedding the UN SDGs within chemistry teaching aligns naturally with ongoing conversations in the discipline about making chemistry more relevant, socially connected, and future-oriented. Framing instruction in this way highlights the

Fig. 1 The 2030 United Nations sustainable development goals (Credit: https://www.un.org/sustainabledevelopment/wp-content/uploads/2019/01/SDG_Guidelines_AUG_2019_Final.pdf).

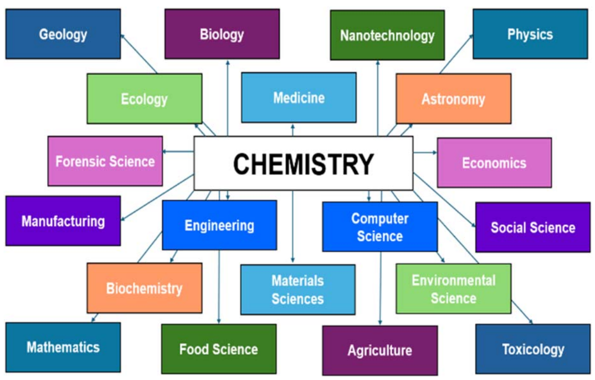

Fig. 2 Illustrating chemistry's interconnections with other disciplines to address sustainability challenges. Figure created by the author.

value of teaching approaches that help students link foundational chemical concepts with wider sustainability challenges.

Why sustainability matters in chemistry curricula

In chemistry education, sustainability has been an essential and recurring theme, demonstrating chemistry's importance in addressing environmental and societal challenges that we face in the world today.[5,6] Sustainability incorporated into the chemistry curriculum enables educators to highlight how important topics such as green chemistry principles can aid in reducing hazardous substances, improving the atom economy, and maximizing renewable feedstocks.[7–9] Promoting such principles in chemistry education encourages students to embrace systems thinking, understand chemical life cycles, and further evaluate how industrial chemical processes have an impact on ecosystems and human health.[7,8,10]

Chemistry education can enhance the relevance and appeal of chemistry to students by linking theoretical concepts learned in classrooms to practical applications such as clean energy, biodegradable materials, and sustainable chemical industries. Incorporating sustainability in chemistry education allows students to see the wider scope of chemistry and how it connects to other branches of science and non-science fields.[3,4]

Countries across the world are prioritizing sustainable development. As a result, students studying chemistry or any other STEM courses need to be taught to become independent thinkers to prepare them to become well-rounded graduates and have meaningful careers in whichever sector they work in.[11,12] Sustainability is not only a pedagogical enhancement but also a key focus in modern chemistry education.

Contemporary developments in chemistry education increasingly emphasize approaches that integrate sustainability challenges, green chemistry concepts, and real-world applications, highlighting the need for curriculum models that meaningfully connect chemical knowledge to sustainable development. The present study contributes to this broader movement by examining how UN SDG-aligned project work can serve as a practical mechanism for strengthening sustainability understanding within undergraduate learning.

In recent years, chemistry education has increasingly moved toward approaches that connect chemical ideas with sustainability themes, green chemistry principles, and practical, real-world contexts. This study contributes to that shift by exploring how project work informed by the UN SDGs can provide a structured pathway for strengthening students' understanding of sustainability within undergraduate chemistry.

Learning preferences and values in sustainability education

Students increasingly value collaborative, technology-enhanced learning environments and benefit from interactive and visual tools.[13] Many learners demonstrate a strong interest in sustainability and seek opportunities to apply STEM knowledge to real-world challenges. Understanding these learning traits allows educators to design experiences that foster engagement and a deeper understanding of chemistry concepts within a sustainability context.[14,15] Table 1 summarizes common

Table 1 Learner traits aligned with targeted teaching strategies for sustainability-focused chemistry education

Learner trait	Teaching strategy	Benefit
Digital-native and multitasking	Use short videos, interactive modules, and simulations	Enhances engagement and simplifies complex chemistry concepts
Hands-on and collaborative	Implement labs, group projects, and real-world problems	Strengthens understanding and connects theory to practical applications
Self-directed and critical	Provide research projects and give personalized choices	Builds autonomy and analytical thinking
Career-oriented and socially aware	Link content to career pathways and global issues	Reinforces relevance and persistence in STEM

Table 2 Student feedback on the environmental science course integrating the UN SDG project

Question	Strongly agree (%)	Agree (%)
The instructor provided a course syllabus that clearly communicated assignments, schedules, and deadlines	66.67	33.33
The instructor presented the course material in a way that helped me learn	100.00	0.00
The instructor organized and presented the course material well	100.00	0.00
The instructor provided timely feedback about my progress in the course	66.67	33.33
The instructor provided useful feedback about my performance on tests, papers*etc.*	66.67	33.33
The exams and assignments in this course are closely aligned with what was on the syllabus	66.67	33.33

learner characteristics and corresponding teaching strategies that support sustainability-focused chemistry education.

Learning experiences that respond to student preferences while engaging them in genuine sustainability issues are now widely viewed as an important element of high-quality chemical education. Such approaches help ensure that graduates are prepared to apply chemistry in ways that are socially responsible and environmentally aware.

Fostering meta-skills in STEM education

Meta-skills development within chemistry and STEM education plays a crucial role in preparing students to address global sustainability challenges, including those reflected in the UN SDGs. When these high-level abilities are embedded in chemistry learning, students are better equipped to think critically, work collaboratively, and apply chemical reasoning to real-world problems. Integrating meta-skills into sustainability-focused chemistry activities further amplifies their value by enabling learners to extend chemical thinking beyond the laboratory and connect scientific understanding to broader societal and environmental issues.

Meta skills are broad, transferable skills that shape how individuals learn, think, and interact. Technical skills are those that are specific to a subject, discipline, or task; meta skills, on the other hand, are high-level abilities that are foundational to lifelong learning.[16] Some examples of meta-skills are critical thinking, resilience, creativity, adaptability, collaboration, and many others.[17] In today's context of a quickly evolving world, meta-skills are deemed of high importance because they empower students to approach complex problems with flexibility and ingenuity, connect ideas across different disciplines, and continuously learn in response to new technologies and discoveries in different areas, and help learners remain agile and innovative.[18]

Incorporating meta-skills in STEM education helps students to prepare for real-world challenges. Problems in STEM are mostly interdisciplinary, vague, and open-ended; as a result, this requires more than subject-based knowledge, but the ability to work with others, think critically, and carry on even after failure.[19] Cultivating meta-skills in students allows them to not only become subject-area experts but also innovative problem solvers and adaptive thinkers.[20]

Promoting meta-skills in STEM education can take place in various ways. This may involve the immediate teaching of meta-skills or integrating meta-skills in classroom environments through project-based learning and reflective practices. Through these approaches, educators can embed meta-skills into STEM learning, which will prepare students for both academic, professional, personal, and social success.[21] Linking meta-skills development with sustainability-focused chemistry activities reflects a broader educational ambition. This enables students to use chemical reasoning in contexts that extend beyond the laboratory. This type of integration supports the development of adaptable, critically minded learners capable of addressing real-world challenges.

To illustrate how chemistry education can advance the United Nations Sustainable Development Goals, this article presents two original projects that were developed for undergraduate STEM students and implemented at the University of the West of Scotland and Wentworth Institute of Technology. The two projects offer context-specific examples of how

Table 3 Representative student comments highlighting relevance, collaboration, skill development, instructor support, and suggested improvements

Theme	Student quote
Relevance and application	"Connecting real-world environmental issues to class concepts through case studies and current events helped me understand the urgency of topics like climate change and sustainability"
Active and collaborative learning	"Collaborative projects and discussions encouraged critical thinking and allowed for different perspectives"
Skill development	"Integration of data and scientific research into assignments helped me develop analytical and research skills"
Instructor support	"Being able to ask the professor for help was very helpful"
Suggestions for improvement	"Extra credit opportunities, more class activities, inclusion of short videos, and flexibility to make up missed labs"

Table 4 Comparison of project characteristics between the two institutions, UWS and WIT

Project characteristics	UWS	WIT
Project format	Group-based (collaborative learning)	Individual-based (independent learning)
Project timeline	Two semesters	Two weeks
Course duration	Two semesters	One semester
Course context	ASPIRE level 8 module	Environmental science course
Course audience	All students studying physical sciences programmes	Only students enrolled in the course
Focus	Global sustainability	Institutional sustainability
Chemistry integration of the UN SDGs	Applied to global UN SDG challenges	Applied to university-level UN SDG evaluation
Assessment	Pass/fail module with detailed rubric	Letter grade with structured rubric
Meta-skills emphasis	Strong focus on meta-skills	Meta-skills embedded in project outcomes

sustainability-driven pedagogies can be adapted across diverse institutional settings to equip students with the competencies needed for addressing global challenges.

The selection of the University of the West of Scotland (UK) and Wentworth Institute of Technology (USA) was intentional, as these two institutions provide contrasting educational contexts in which the author has directly taught and implemented the sustainability and UN SDG-aligned instructional approaches presented in this study. Their differences in student demographics, institutional missions, and curricular structures created an opportunity to examine how chemistry-based, meta-skills-centred pedagogies can be adapted to support UN SDG-focused learning across varied environments. The two universities act as a case study to strengthen the applicability and transferability of this instructional model by demonstrating its effectiveness in advancing UN SDG-oriented competencies across diverse cohorts and institutional settings.

The university of the West of Scotland (UK)

The University of the West of Scotland (UWS) is a modern public university with campuses in Paisley, Lanarkshire, Dumfries, Ayr, and London. Serving over 16 700 students, UWS is

Table 5 Summary of UWS student challenges linking chemistry concepts to relevant UN SDGs and sustainability outcomes

Challenge	UN SDGs	Link to chemistry topics	Project results
Challenge 1: knocking the wind out of the UK	SDG 7, 9, 13	Electrochemistry, materials chemistry, thermodynamics	Develop renewable energy solutions; design efficient wind turbine materials; reduce carbon emissions
Challenge 2: wave goodbye to fresh water	SDG 2, 6, 13	Water chemistry, environmental chemistry, analytical chemistry	Improve water purification methods; monitor water quality; support sustainable agriculture
Challenge 3: putting the 'hydrogen' in hydrogen powered vehicles	SDG 7, 9, 13	Catalysis, physical chemistry	Advance hydrogen fuel technology; reduce fossil fuel dependence; promote clean transportation
Challenge 4: more precious than silver and gold	SDG 8, 9, 12	Inorganic chemistry, green chemistry	Develop sustainable mining practices; recycle critical materials; reduce environmental impact
Challenge 5: from farm to fork	SDG 2, 3, 12	Organic chemistry, environmental chemistry	Enhance food security; reduce pesticide contamination; promote sustainable farming
Challenge 6: Scotland's NHS nightmare	SDG 3, 9, 16	Biochemistry, analytical chemistry, medicinal chemistry	Improve drug safety; develop rapid diagnostic tools; strengthen healthcare systems
Challenge 7: making your mark	SDG 3, 10, 16	Forensic chemistry, analytical chemistry, polymer chemistry	Advance forensic analysis; ensure justice through science; improve trace evidence detection
Challenge 8: teachers without borders	SDG 4, 9, 10	General chemistry, physical chemistry, green chemistry	Expand STEM education access; promote inclusive learning; integrate sustainability in curricula
Challenge 9: ending period poverty	SDG 3, 5, 12	Polymer chemistry, organic chemistry, green chemistry	Develop affordable sanitary products; reduce plastic waste; support gender equality
Challenge 10: show your true colours	SDG 3, 12, 13	Organic chemistry, food chemistry	Create safe food colorants; reduce chemical additives; support sustainable food production

Table 6 Summary of WIT student projects linking chemistry concepts to UN SDGs and sustainability outcomes

UN SDG	Link to chemistry topics	Project results
SDG 2	Analytical chemistry, food chemistry	Analyze nutrients in local food; test soil for urban gardens; develop biodegradable packaging
SDG 3	Environmental chemistry	Monitor air and water quality; study PFAS and microplastics; design safer biomedical materials
SDG 4	General chemistry	Create STEM outreach kits; publish open-access lab manuals; embed green practices in labs
SDG 5	Lab safety and ethics	Ensure equitable lab participation; track gender representation; mentorship for underrepresented groups
SDG 6	Analytical chemistry	Monitor local waterways; develop low-cost sensors; improve water treatment methods
SDG 7	Thermochemistry	Research battery materials; explore solar photocatalysis; conduct energy audits
SDG 8	General chemistry	Partner with industry for safer processes; train in QA/QC standards; promote green chemistry
SDG 9	Materials chemistry	Prototype sustainable materials; optimize catalytic processes; host innovation hackathons
SDG 12	Green chemistry	Implement green lab programs; control chemical inventory; perform lifecycle assessments
SDG 13	Analytical chemistry, environmental chemistry	Track campus green house gas emissions; experiment with carbon capture; research climate-resilient materials

recognized for robust industry partnerships and a strong commitment to social inclusion. The university comprises four schools: Business and Creative Industries (BCI), Computing, Engineering and Physical Sciences (CEPS), Education and Social Sciences (ESS), and Health and Life Sciences (HLS).[22]

Within CEPS (Paisley campus), the author, who was previously a Lecturer in Environmental Science, designed the ASPIRE

Table 7 Summary of study limitations and considerations for future adaptation

Limitation area	Description	Possible improvements
Data constraints	UWS data could not be accessed due to institutional data-protection policies; formal survey and performance metrics are unavailable	Work with institutions to obtain ethics approval or anonymized datasets; embed micro-assessments during project work
Cohort size	Small cohort at WIT ($N = 7$) limits generalization	Larger or multi-section cohorts could validate findings across student populations
Assessment design	No pre- or post-measures of chemistry learning, meta-skills development, or UN SDG literacy	Incorporate validated UN SDG literacy scales or concept inventories; use structured rubrics to quantify learning
Evidence type	Learning is demonstrated through project outputs (Tables 5 and 6, SI) rather than empirical testing	Combine project artifacts with coded qualitative data or structured quizzes
Project structure differences	UWS and WIT differed in format, duration, assessment, and disciplinary composition	Institutions replicating the model can harmonize project parameters to enable comparison across contexts
Interdisciplinary cohorts	Students came from diverse STEM fields, limiting chemistry-specific conclusions	Use discipline-specific cohorts when focusing on chemistry learning outcomes
Instructor dual role	The instructor served as designer, facilitator, and evaluator, which may introduce practitioner-researcher bias	Incorporate co-assessment, external reviewers, or anonymized grading
Long-term impact	No longitudinal tracking to measure sustained chemistry-UN SDG engagement or meta-skills retention	Future work could follow students across courses or years
Adaptation variability	The framework requires contextual adaptation and may be implemented differently elsewhere	Flexibility is a strength; other educators can refine project design and address local constraints

Table 8 Recommendations for future curriculum design

Key curriculum recommendation	UN SDG-aligned rationale
Embed the united nations sustainable development goals and contextualize them across all STEM disciplines	This fosters global awareness and promotes interdisciplinary thinking by encouraging learners to critically examine the societal and environmental implications of the UN SDGs and relate them to their area of study
Establish a balance between group-based and individual project formats	This accommodates diverse learning preferences while ensuring that all students can meaningfully engage with UN SDG-driven sustainability problems. Collaborative projects support collective problem-solving around UN SDG targets, while individual work strengthens personal accountability for UN SDG-aligned scientific reasoning
Emphasize a range of useful meta-skills development	Meta-skills such as critical thinking, adaptability, and communication directly support students' ability to design, evaluate, and justify solutions to UN SDG-related chemistry challenges
Integrate more real-world challenges into the curriculum	Real-world sustainability scenarios help students apply chemistry principles to authentic UN SDG targets, thereby bridging classroom learning with global and local sustainability needs. Expanding the variety of UN SDG-linked challenges strengthens students' ability to develop practical, evidence-based solutions to sustainability problems
Reconstruct assessment strategies for the projects	UN SDG-aligned assessment models, such as performance-based evaluations, reflective components, and peer review, capture the full complexity of students' sustainability problem-solving. These approaches better measure UN SDG-related competencies than traditional rubrics alone

Level 8 module, which includes the "Applying UN SDGs to Solve Global Challenges" group project and a suite of twenty meta-skills. The work was piloted with second-year undergraduate Physical Sciences students studying in the following programmes: Chemistry, Chemistry with Education, Mathematics, Mathematics with Education, Physics, Physics with Nuclear Technology, Physics with Education, and Criminal Justice and Forensic Science. ASPIRE (Academic and Skills Programme for Industry Ready Employability) is a university-wide initiative focused on academic, professional, and personal development. The sustainability-focused group project was embedded over one semester and aligned with the UN SDGs.

Project design

The project employed a project-based learning approach to foster sustainability literacy and problem-solving skills. By engaging participants in real-world challenges aligned with the UN SDGs, the methodology integrated disciplinary chemistry knowledge with student collaboration and practical application.

Students worked in groups to select one of ten contemporary challenges that reflect critical global issues. Challenges were intentionally framed within diverse geographic and social contexts to promote global awareness and creativity.

Each group completed a structured project plan comprising four components:

(1) Personal SWOT analysis: A SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) was used to support reflection on individual contributions and group dynamics. Students identified strengths, acknowledged weaknesses, and considered external opportunities and threats. This process enhanced planning and cultivated meta-skills, including critical thinking, strategic decision-making, problem-solving, and self-awareness.

(2) Five-part project plan: the plan guided systematic progress through: (1) overview of the UN SDGs; (2) justification for the selected challenge; (3) proposed solutions; (4) alignment with specific UN SDGs; and (5) anticipated risks and mitigation strategies. The framework promoted collaboration, equitable participation *via* roles and timelines, and accountability.

(3) Presentation component: groups presented findings in a class seminar to strengthen scientific communication, public engagement, and digital literacy while building confidence in articulating sustainability solutions.

(4) Meta-skills reflection: students documented and reflected on meta-skills developed during the module. Meta-skills were embedded as essential competencies to prepare learners for a rapidly evolving workforce.

Measuring learning outcomes

The ASPIRE Level 8 module learning outcomes can be divided into two distinct categories: (1) the ASPIRE Level 8 Module and (2) the UN SDG group project.

(1) ASPIRE Level 8 Module Learning Outcomes:

- Reflective thinking and self-awareness in relation to academic/professional goals.
- Academic Professional and Personal Development (APPD): understanding of career pathways and required skills/experiences.
- Collaborative problem-solving on real-world challenges aligned with the UN SDGs.
- Critical thinking and innovation in designing evidence-based solutions.

- Communication and presentation skills *via* written plans and oral dissemination.

- Meta-skills development across competencies.

(2) UN SDG Group Project Learning Outcomes:

- Understanding of the UN SDGs as a global sustainability framework and its relevance.

- Challenge identification and justification with societal/environmental/economic significance.

- Solution design and innovation through interdisciplinary collaboration and creative thinking.

- Strategic planning and implementation outlining objectives, methods, resources, and timelines.

- Impact analysis and explicit alignment to specific UN SDGs and ethical responsibilities.

- Contingency planning and risk evaluation, ensuring feasibility and resilience.

- Communication and collaboration demonstrated in written and oral outputs.

Full details are provided in the SI.

Integration into the curriculum

ASPIRE Level 8 is a skills-focused academic enrichment program designed to foster personal growth, academic excellence, and collaborative learning. The curriculum began with the introduction of the UN SDG group project and continued through advising sessions, lectures, and interactive activities across two semesters, including contributions from guest speakers in academia and industry.

The module included 36 hours of synchronous learning (tutorials and project sessions), 164 hours of independent study (research, planning, reflection), and 12 hours of APPD tutorials. Weekly sessions targeted competencies in collaboration, innovation, academic integrity, and well-being. Reflective practice was embedded throughout, culminating in a seminar presentation where groups showcased solutions to their selected UN SDG-related challenges.

Project overview: "Applying UN SDGs to Solve Global Challenges"

The 2030 United Nations Sustainable Development Goals provide a global framework for achieving a sustainable future by addressing poverty, protecting the planet, and promoting peace and prosperity. Their relevance spans all disciplines, making them essential for students across higher education.

The University of the West of Scotland (UWS) emphasizes producing "work-ready" graduates equipped with interdisciplinary skills. To support this vision, a challenge-based project was developed to enable students to engage with real-world problems inspired by the UN SDGs. These challenges were designed to integrate academic research, innovative thinking, and practical application. Participation in the project aimed to:

- Deepen understanding of sustainability and global citizenship.

- Strengthen critical thinking, teamwork, and problem-solving skills.

- Apply chemistry disciplinary knowledge to complex, interdisciplinary scenarios.

- Build confidence in collaboration and scientific communication.

Assessment strategy

Assessment was based entirely on the UN SDG group project and submitted *via* PebblePad (web-based e-portfolio). The portfolio comprised three components:

- Group project plan (46%): evaluates collaborative planning and organization.

- Project presentation (18%): assesses scientific communication and dissemination.

- Record of meta-skills (36%): encourages reflection and documentation of transferable skills.

Full details are found in the SI.

Project methodology

This project was designed as a project-based learning approach to foster sustainability literacy and problem-solving skills. By engaging participants in real-world challenges aligned with the United Nations Sustainable Development Goals (UN SDGs), the methodology aimed to combine academic rigor with practical application, encouraging interdisciplinary collaboration and innovative thinking.

Ten contemporary challenges were presented, each reflecting critical global issues such as renewable energy, water security, resource management, and social equity. Participants worked collaboratively in groups to select one challenge and develop innovative, sustainable solutions. Comprehensive descriptions of the challenges are in the SI.

- Challenge 1: knocking the wind out of the UK – renewable energy affordability in the UK.

- Challenge 2: wave goodbye to fresh water – freshwater scarcity in the Pacific Islands.

- Challenge 3: putting the "Hydrogen" in hydrogen powered vehicles – green hydrogen production for transportation.

- Challenge 4: more precious than silver and gold – Sustainable management of rare earth elements.

- Challenge 5: from farm to fork – improving local food production systems.

- Challenge 6: Scotland's NHS nightmare – data recovery and management in healthcare.

- Challenge 7: making your mark – forensic solutions for criminal investigations.

- Challenge 8: teachers without borders – STEM education in resource-limited settings.

- Challenge 9: ending period poverty – biodegradable menstrual products from agricultural waste.

- Challenge 10: show your true colours – natural food colour extraction for vegan bakery products.

Groups were tasked with analysing the selected challenge, proposing feasible solutions, and presenting their findings through a structured project plan and seminar presentation. The project plan comprised of these five sections:

(1) Overview of UN SDGs and their relevance to global sustainability.

(2) Selected challenge and justification for its importance.

(3) Proposed solutions and implementation strategies.

(4) Alignment with relevant UN SDGs.

(5) Potential risks and mitigation strategies.

The work was presented in four parts:

- Part 1: SWOT analysis – each participant conducted a personal SWOT analysis to reflect on their anticipated contribution in the group project, listing five concise points under Strengths, Weaknesses, Opportunities, and Threats.

- Part 2: project plan – a detailed 2500-word collaborative plan structured around the five sections.

- Part 3: seminar presentation–a 15-minutes group presentation summarizing the challenge and proposed solutions, supported by visual aids.

- Part 4: meta-skills development–participants selected 12 meta-skills from a predefined list of 20 meta-skills and completed their respective activities as independent asynchronous learning. List of meta-skills: Abstract Writing, Applying for Funding, Critical Reading and Thinking Skills, CV/Resume Writing, Data Handling Skills, Emotional Intelligence, Financial Literacy, Global Citizenship, Interview Techniques, Lab Safety Skills, Leadership and Teamwork Skills, Public Engagement Skills, Referencing and Citation Skills, Reflective Writing Skills, Research Proposal Writing, Science Communication and Presentation Skills, Scientific Writing Skills, Social Media (LinkedIn and Twitter), STEM Research Ethics, and Time Management Skills. Each member produced a reflective summary outlining key insights and the meta-skills they chose, and their relevance to academic and professional development.

Further details are provided in the SI.

Student feedback and reflections

Students in the Physical Sciences division at the University of the West of Scotland responded positively to the ASPIRE Level 8 module, which featured the Applying UN SDGs to Solve Global Challenges project as its centerpiece. Due to large enrollment, exact quantitative and qualitative results could not be obtained, which poses a limitation. Instead, a general overview was compiled from reflective e-portfolio comments and post-project class discussions. Feedback was unanimously favorable, and students said that the project was highly enjoyable.

Students highlighted the module's emphasis on personal development, transferable skills, and real-world application through the UN SDG project. Many described the experience as transformative, encouraging holistic thinking about global issues and strengthening academic and professional aspirations. The project was widely regarded as the most engaging component, offering opportunities to work collaboratively on authentic challenges and apply knowledge creatively. Students reported that the project fostered innovative thinking, teamwork, and global awareness.

Alongside sustainability literacy, students emphasized that meta-skills built their confidence and were essential for career readiness. Collectively, this feedback underscores the value of embedding sustainability-focused, project-based learning into STEM education to prepare graduates for global challenges aligned with the UN SDGs.

While reflective statements and peer evaluations were not collected, digital artifacts of student work serve as evidence of learning outcomes. These include presentation slides and project deliverables submitted during the sustainability challenge. These materials illustrate students' ability to apply green chemistry principles, align solutions with UN SDGs, and communicate findings effectively. Representative examples are provided in the SI.

Wentworth Institute of technology (USA)

Wentworth Institute of Technology (WIT), founded in 1904, is a private university located in Boston, Massachusetts, with a student population of approximately 4000. WIT comprises of five schools: Architecture and Design, Computing and Data Science, Engineering, Management, and Sciences and Humanities. The university is recognized for its strong emphasis on experiential and cooperative education, maintaining over 266 industry partnerships and incorporating two co-op semesters into its curriculum. Wentworth delivers career-focused, interdisciplinary learning through well-equipped laboratories, studios, and real-world projects, preparing students to become skilled and engaged professionals.[23]

The author currently serves as an Assistant Professor of Chemistry in the School of Sciences and Humanities and designed the Environmental Science course. This introductory science course provides foundational knowledge across biology, chemistry, physics, and geology, with a focus on environmental principles such as human–environment interactions, anthropogenic pollutants, climate systems, biodiversity, natural resources, food security, energy sources, green technologies, and sustainable communities. Offered as a science elective, the Environmental Science course is accessible to WIT students across multiple majors and supports WIT's commitment to sustainability by equipping students with scientific literacy to address contemporary environmental challenges.

Project design

As part of the Environmental Science course, the author designed an adapted version of the UN SGD project. This project investigated how WIT can contribute meaningfully to achieving selected UN SDGs within its campus context. WIT maintains a campus-wide sustainability agenda through institutional practices, academic programs, research initiatives, and community engagement. The project was aligned with WIT's strategic pillars: preparing students for success, contributing to society, and evolving as a learning institution.

The project focused on ten pre-selected UN SDGs: Zero Hunger (SDG 2), Good Health and Well-being (SDG 3), Quality Education (SDG 4), Gender Equality (SDG 5), Clean Water and Sanitation (SDG 6), Affordable and Clean Energy (SDG 7), Decent Work and Economic Growth (SDG 8), Industry, Innovation and Infrastructure (SDG 9), Responsible Consumption and Production (SDG 12), and Climate Action (SDG 13). These goals were selected to enable students to apply chemistry concepts and interdisciplinary approaches to assess WIT's alignment with global sustainability objectives critically. Students were tasked with proposing actionable and realistic recommendations to enhance WIT's role in advancing sustainable development locally and globally.

The project was designed around a project-based learning framework aligned with the course and WIT's strategic pillars.

- Individual project work: students worked independently, selecting one of the pre-selected UN SDGs. This approach fostered autonomy, initiative, and critical engagement with sustainability issues. By tailoring their work to personal interests, students analysed how their chosen SDG could be implemented within WIT's context.

- Project work structure: the project consisted of four stages.

(A) Knowledge acquisition – students conducted independent research on their selected SDG, reviewing a minimum of six articles to understand global targets and implementation strategies.

(B) Contextual application – students critically analysed WIT's sustainability initiatives, such as academic programs, research areas, infrastructure, and community partnerships, to identify strengths, gaps, and opportunities for alignment with the chosen SDG.

(C) Solution development – students proposed actionable, feasible, and measurable recommendations for integrating the SDG into WIT's operations, demonstrating systems thinking and considering unintended consequences. Recommendations addressed areas such as curriculum design, student engagement, research, campus initiatives, and community partnerships.

(D) Communication and reflection – students presented their findings in a 10-minute seminar presentation followed by a 5-minute Q&A session. This component strengthened public speaking, scientific communication, and reflective practice. The written deliverable was a 2500-word report synthesizing research, contextual analysis, and proposed solutions, reinforcing academic writing and critical thinking skills.

Further details are provided in the SI.

Measuring learning outcomes

The project's learning outcomes were designed to advance global sustainability awareness, interdisciplinary thinking, problem-solving, independent learning, innovation, and Academic, Professional, and Personal Development (APPD) through meta-skills integration.

(1) Understanding global sustainability frameworks: students demonstrated a clear understanding of the 2030 United Nations Sustainable Development Goals, their interconnectivity, and relevance to global challenges.

(2) Problem-solving: students applied interdisciplinary knowledge to address campus-based challenges aligned with their chosen UN SDG.

(3) Communication and presentation skills: students enhanced their ability to communicate ideas effectively through structured written reports and oral presentations.

(4) Creative thinking and innovation: students independently developed innovative, feasible, and sustainable solutions for implementing their chosen UN SDG within the university context and integrating chemistry concepts.

(5) Strategic planning and implementation: students formulated actionable recommendations and strategic plans for implementing proposed solutions.

(6) Impact analysis and goal alignment: students assessed how their proposed solutions contributed to institutional sustainability efforts and aligned with global goals, demonstrating awareness of global citizenship, community engagement, and ethical responsibility.

Integration into the curriculum

An environmental science course was designed to provide a comprehensive understanding of the interplay between scientific principles and environmental challenges. The curriculum introduced foundational concepts in ecology and ecosystems, emphasizing biodiversity and the intrinsic value of natural systems, as well as strategies for their preservation and restoration. Subsequent modules examined the implications of human population growth on natural resources, including water, soil, food production, and pest management. Additional topics included energy consumption, the transition to renewable energy sources, global climate change, environmental hazards, chemical pollution, and the management of solid and hazardous waste. The course concluded with a focus on sustainable communities, encouraging students to adopt interdisciplinary approaches and practical solutions for a sustainable future.

The United Nations Sustainable Development Goals were integrated clearly throughout the course, providing a global framework for contextualizing sustainability challenges. The one-semester course consisted of 35 hours of synchronous lectures and 23 hours of synchronous laboratory activities. Weekly topics were aligned with specific learning outcomes.

Assessment strategy

Assessment was based on a sustainability-focused group project aligned with the UN SDGs. The project accounted for 15% of the overall course grade and was evaluated using three components:

- Written report (60%): assesses research, critical analysis, and application of SDGs within an institutional context.

- Oral presentation (30%): evaluates scientific communication, presentation design, and delivery.

- Q&A interaction (10%): measures depth of understanding and ability to respond analytically under pressure.

Full assessment criteria are provided in the SI.

Project overview: "Applying UN SDGs to Tackle Sustainability Challenges Across Wentworth Institute of Technology"

The project titled "Applying UN SDGs to Tackle Sustainability Challenges Across Wentworth Institute of Technology" was designed to engage undergraduate students enrolled in the Environmental Science course in a multidisciplinary exploration of sustainability. The project centered on the application of the UN SDGs within the context of WIT, encouraging students to assess institutional practices and propose actionable recommendations for improvement critically.

Students were tasked with selecting one of ten pre-selected UN SDGs. They then applied foundational chemistry concepts to evaluate WIT's current sustainability efforts related to their selected UN SDG. The task emphasized project-based learning to foster a deeper understanding of the UN SDGs.

Project methodology

This project, "Applying UN SDGs to Tackle Sustainability Challenges Across Wentworth Institute of Technology", was designed to explore how global sustainability efforts can be applied within a local institutional context. The aim was to integrate chemistry knowledge and innovative thinking to assess Wentworth Institute of Technology's alignment with the United Nations Sustainable Development Goals and identify opportunities for improvement.

Participants selected one UN SDG from the following list: UN SDG 2: Zero Hunger; UN SDG 3: Good Health and Well-Being; UN SDG 4: Quality Education; UN SDG 5: Gender Equality; UN SDG 6: Clean Water and Sanitation; UN SDG 7: Affordable and Clean Energy; UN SDG 8: Decent Work and Economic Growth; UN SDG 9: Industry, Innovation and Infrastructure; UN SDG 12: Responsible Consumption and Production; UN SDG 13: Climate Action. The task involved five steps:

(1) Research – review at least five peer-reviewed journal articles related to the chosen UN SDG.

(2) Institutional analysis – examine WIT's current efforts toward the selected UN SDG.

(3) Gap identification – highlight strengths, weaknesses, and areas for improvement.

(4) Recommendations – propose actionable strategies to enhance alignment with the UN SDG.

(5) Implementation plan – outline practical steps for executing the recommendations.

The project deliverables included a written report (2500 words) and a 10-minute class presentation followed by a 5-minutes Q&A session. The written report comprised:

- Introduction to the chosen UN SDG.
- Analysis of Wentworth's current alignment.
- Identification of gaps and opportunities.
- Recommendations and implementation plan.
- APA-style references.

Comprehensive details are provided in the SI.

Student feedback and reflections

Student feedback was collected through an anonymous post-course survey that included both Likert-scale questions and open-ended reflections. Responses provided insight into the perceived impact of the UN SDG project on learning and skill development.

(1) Quantitative summary. As part of the Environmental Science course, students engaged in the UN SDG project. A total of seven students were enrolled in the course and participated in the project, which reflects the typical cohort size for this upper-level elective and supports intensive project-based learning. To evaluate the overall course experience, which included the UN SDG project as a core component, students completed a survey using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The feedback reflects the combined experience of the course and project. While the survey did not include project-specific items, the responses capture students' perceptions of course organization, instructional quality, and support during the UN SDG project. The summary of these responses is presented in Table 2. Overall, the feedback indicates strong satisfaction with course delivery and suggests that the integration of the UN SDG project was well-received by students.

While Table 2 reflects the students' perceptions of course delivery, evidence of UN SDG-specific learning is demonstrated through the project outputs summarised in Table 6. All students successfully identified relevant UN SDGs, linked them to appropriate chemistry concepts, and proposed practical sustainability solutions. These outputs provide clear evidence that students applied their chemistry knowledge to UN SDG-aligned sustainability challenges.

(2) Qualitative summary. Students provided open-ended responses in the course survey to share their perspectives on the Environmental Science course, which integrated the UN SDG project as a core component. These comments (shown in Table 3) reflect the combined experience of the course and project. Key themes included the real-world relevance of sustainability concepts, opportunities for active and collaborative learning, and the development of research and analytical skills. Students also emphasized the value of instructor support and suggested improvements such as clearer rubrics, more time for project work, and additional interactive resources. Overall, the qualitative feedback indicates that the UN SDG project enhanced engagement and enriched the learning experience.

Survey results demonstrate high satisfaction with course organization and instructional support, with "Strongly Agree" responses exceeding 66% for most items and reaching 100% for clarity of material and course structure. These findings indicate that the course design and delivery were highly effective.

Qualitative feedback from open-ended survey responses consistently identified the project as the most engaging and impactful component of the course. Students verbally reported that the project helped them connect chemistry concepts to sustainability challenges and appreciate the relevance of the UN SDGs at both global and local levels. Initially perceived by students as distant policy goals, the UN SDGs became tangible through institutional actions proposed by students.

The project enabled the application of chemistry knowledge to practical environmental issues, deepening understanding of chemistry's role in sustainability. Reviewing scientific literature exposed students to innovative approaches in green chemistry and sustainable technologies, while developing actionable recommendations for Wentworth Institute of Technology fostered critical thinking and systems-level analysis. Students verbally expressed gains in valuable skills such as academic writing, research, communication, global citizenship, and problem-solving skills. Evidence of student learning at WIT is demonstrated through selected examples provided in the SI.

Discussion

This cross-institutional comparison between the University of the West of Scotland and Wentworth Institute of Technology underlines the adaptability and transformative potential of sustainability-focused chemistry education when engaging undergraduate students. The projects "Applying UN SDGs to Solve Global Challenges" and "Applying UN SDGs to Tackle Sustainability Challenges Across Wentworth Institute of Technology" were carried out respectively at UWS and WIT to embed the UN SDGs into curriculum design to purposely cultivate globally conscious, scientifically literate, and professionally competent graduates to enter a sustainability-focused workforce and a rapidly evolving world.

Comparative insights and adaptations

The UWS project highlighted a group and collaborative learning approach focused on global problem-solving. In contrast, WIT, on the other hand, emphasized independent and individual learning, with its project focusing on a local institutional impact. Both adaptations are distinct but generally reflect each institution's strategic priorities and the needs of its STEM students, which demonstrate valuable approaches to flexible curriculum design. The different instructional formats at UWS and WIT nonetheless centered the UN SDGs as the unifying framework, guiding both global and institutional sustainability problem-solving. Together, these adaptations demonstrate that despite structural differences between institutions, the UN SDGs remained the central organizing framework guiding both the pedagogical design and the chemistry-based problem-solving tasks (Table 4).

Linking concepts: chemistry integration and project results

At the University of the West of Scotland, students worked on ten contemporary challenges that reflect global issues, including renewable energy, water security, resource stewardship, and educational equity. Table 5 illustrates how each challenge was explicitly connected to relevant UN SDGs, chemistry concepts, and the sustainability outcomes that the UWS students suggested. These mappings show how students integrated core chemistry principles into real-world sustainability problems, reinforcing project-based learning.

At Wentworth Institute of Technology, Environmental Science students adapted the UN SDG challenge framework to the campus context. Projects were mapped to selected UN SDGs and chemistry topics to clarify integration and highlight sustainability outcomes. This alignment ensured that students connected theoretical knowledge with practical strategies for advancing WIT's sustainability agenda. Table 6 highlights Environmental Science projects at WIT, demonstrating how students linked selected UN SDGs to chemistry topics and the results they suggested. This alignment ensured that projects were grounded in disciplinary knowledge while promoting practical solutions for campus sustainability and advancing global goals.

These project outputs provide observable evidence of student learning and progress toward the intended SDG-aligned outcomes. All students were able to identify relevant UN SDGs, connect them to appropriate chemistry concepts, and propose practical sustainability solutions, demonstrating measurable application of knowledge. The projects summarized in Tables 5 and 6 show that students could interpret global and institutional sustainability challenges and translate them into chemistry-informed actions. This evidence directly supports the assertions made regarding student learning, even though UN SDG-specific survey items were not included in the course evaluation.

Challenges and opportunities in sustainability-focused chemistry education

The challenges and opportunities for assessment design in sustainability-focused chemistry education are prevalent. Addressing these helps to create a more dynamic, inclusive, and impactful learning environment for students.

One of the key challenges was balancing the depth of the project's content with students' accessibility. When designing the projects, the author aimed to provide rigorous academic content but also make it understandable and engaging for all students. This, on the other hand, provided an opportunity for students to engage in interdisciplinary learning across various subjects, thereby deepening their understanding. These assessment and engagement challenges directly influenced how effectively students could apply chemical principles to UN SDG-aligned sustainability problems.

The two projects have a traditional assessment rubric, which was both advantageous and disadvantageous. The advantages were: clarity and transparency, consistency and fairness, efficiency for educators, structured feedback tools, and alignment with learning outcomes. The disadvantages, on the other hand, were limited flexibility, overemphasis on measurable criteria, risk of constraining creativity, and potential bias when marking. Another significant challenge for sustainability-focused chemistry education is designing varied and inclusive forms of student engagement and assessment that support flexible learning. When assessing non-traditional work such as models, visuals, prototypes, or interactive projects, traditional marking rubrics are insufficient. Consequently, this limitation can become an opportunity for educators to design innovative assessment strategies that are inclusive of innovative, creative, and novel work.

The planning, implementing, and providing guidance for the two separate projects proved to be complex and time-consuming. Alternatively, the author found satisfaction working with students on these projects because they promoted student ownership and nurtured creativity and problem-solving. Students were given the autonomy to shape their own projects, and this increased engagement and motivation in their work.

Finally, an opportunity to improve the quality and depth of student projects, allocation of resources for project work would have resulted in a more significant output. Rather than limiting students to traditional assessment formats, providing additional resources would have enabled them to build creative models or develop prototypes to fully implement their ideas. This would have fostered exceptional student engagement and a comprehensive understanding of the project.

Limitations

As with all practice-based educational research embedded in real classroom settings, this study operated within constraints. Table 7 summarizes these limitations and how this work can be refined and adapted in diverse teaching contexts.

Implications for future curriculum design

Looking into the future, the curriculum must integrate several key strategies to prepare students for future challenges and shape them into becoming well-rounded individuals. Table 8 outlines key curriculum design recommendations targeted at advancing sustainability-focused chemistry education, and their corresponding justifications.

Conclusions

To illustrate how chemistry education can advance the United Nations Sustainable Development Goals and respond to emerging priorities in sustainable chemistry teaching, this article presents two original projects developed for undergraduate STEM students. These projects were designed to help students connect core chemical concepts with broader sustainability challenges, demonstrating how UN SDG-aligned tasks can strengthen both disciplinary understanding and sustainability literacy. Together, they show how chemistry curricula can offer meaningful, future-oriented learning experiences that empower students to apply chemistry in socially and environmentally responsible ways.

The University of the West of Scotland in the United Kingdom and Wentworth Institute of Technology in the United States are two distinct transatlantic institutions. When comparing the cross-institutional implementation of the projects, chemistry and sustainability education thrived when students were presented with meaningful and context-rich challenges. Despite differences in project characteristics, both projects fostered deep learning and engagement and nurtured skill development in students. The two projects emphasized project-based learning and real-world relevance and application, which were paramount to student success and satisfaction. This affirms the learning styles of students, who are motivated by opportunities to connect their education with solving real-world challenges using chemistry as a tool.

In the future, curriculum development should continue to prioritize sustainability as a foundational theme and use chemistry to address imperative societal and environmental challenges. Students' learning experiences must be contextualized within authentic global issues so they can connect their chemistry knowledge with global citizenship responsibility and career readiness. A balanced combination of group and individual projects can accommodate diverse learning techniques, foster collaboration and independent learning, and encourage reflective practice.

Moreover, cultivating meta-skills is essential for preparing students to address complex scientific and societal challenges. Assessment methods should incorporate reflective components, peer evaluations, models and prototypes, and digital portfolios, to provide a more holistic view on student development and learning.

Future research should explore the long-term impacts of sustainability-oriented chemistry education on students' careers, community involvement, and scientific knowledge that resonate with learners. Finally, sustainability-focused chemistry education provides a powerful platform for empowering the next generation of STEM leaders to innovate with purpose and address the multifaceted global challenges.

Author contributions

The author solely designed the projects presented in this work and is fully responsible for the preparation of this manuscript.

Conflicts of interest

The author declares no conflicts of interest.

Data availability

All data supporting the findings of this study are included within the manuscript.

Supplementary information (SI) is available. See DOI: https://doi.org/10.1039/d5su00954e.

References

1 S. A. Matlin, G. Mehta, H. Hopf and A. Krief, *Eur. J. Inorg. Chem.*, 2019, **2019**, 4170–4173, DOI: 10.1002/ejic.201801409.
2 U. P. Ogodo and O. O. Abosede, *Int. Res. J. Pure Appl. Chem.*, 2025, **26**, 1–8, DOI: 10.9734/irjpac/2025/v26i1893.
3 Principles for Responsible Management Education (PRME), *UN Global Compact, launched 2007, >800 signatories in 90+*

countries, https://unglobalcompact.org/what-is-gc/our-work/managment-education, accessed 7 November 2025, 2007.
4 Royal Society of Chemistry, *Embedding Sustainability in Chemistry Education" a Roundtable*, RSC News, February 2025, https://www.rsc.org/news/2025/february/embedding-sustainability-in-chemistry-education-a-roundtable, accessed 7 November 2025.
5 P. G. Mahaffy and S. A. Matlin, *Systems Thinking in Chemistry Education: Preparing Global Citizens for a Sustainable Future, ACS Green Chemistry Institute webinar slides*, Dec. 10 2020, https://www.acs.org/content/dam/acsorg/acs-webinars/2020/slides/2020-12-10-gci-systems-thinking.pdf, accessed 7 November 2025.
6 P. G. Mahaffy, S. A. Matlin, J. M. Whalen and T. A. Holme, *J. Chem. Educ.*, 2019, **96**(12), 2730–2741, DOI: 10.1021/acs.jchemed.9b00390.
7 P. T. Anastas and J. C. Warner, *Green Chemistry: Theory and Practice*, Oxford University Press, 2000.
8 C. Widyantoro, J. Y. Han, J. S. H. Ong, K. H. Goh and F. M. Fung, *J. Chem. Educ.*, 2025, **102**, 2743–2754, DOI: 10.1021/acs.jchemed.5b00000.
9 F. A. Etzkorn and J. L. Ferguson, *Angew. Chem., Int. Ed.*, 2023, **62**(2), e202209768, DOI: 10.1002/anie.202209768.
10 J. E. Hutchison, *J. Chem. Educ.*, 2019, **96**, 2777–2783, DOI: 10.1021/acs.jchemed.9b00334.
11 R. Sánchez Morales, P. Sáenz-López and M. A. de las Heras Perez, *Sustainability*, 2024, **16**, 6526, DOI: 10.3390/su16156526.
12 M. Mitarlis, U. Azizah and B. Yonata, *J Technol Sci Educ*, 2023, **13**, 233, DOI: 10.3926/jotse.1892.
13 Walton Family Foundation & Gallup, Gen Z Perspectives on STEM Education, *NextGen Insights*, December 2023, https://nextgeninsights.waltonfamilyfoundation.org/resources/perspectives-on-stem/, accessed 7 November 2025.
14 S. Chardonnens, *Front. Educ.*, 2025, **10**, 1504726, DOI: 10.3389/feduc.2025.1504726.
15 C. Seemiller, M. Grace, P. Dal Bo Campagnolo, I. Mara Da Rosa Alves and G. Severo De Borba, *Int. J. Educ. Pol. Res. Pract.*, 2019, **9**(1), 349–368, DOI: 10.5590/JERAP.2019.09.1.25.
16 M. Senova and J. B. Econ, *Soc. Syst.*, 2020, **2**, 133–137.
17 E. Spencer and B. Lucas, *Meta-Skills: Best practices in work-based learning A literature review, commissioned by Skills Development Scotland*, 2021, p. , p. 72, available via University of Winchester, https://cris.winchester.ac.uk/ws/portalfiles/portal/12520973/Spencer_and_Lucas_2021_Meta_skills_literature_review_SDS.pdf, accessed 7 November 2025.
18 R. Whitney and S. Watt, *ASPIRE: A Cross-Institutional Approach to Embedding Employability Skills at UWS*, University of the West of Scotland, 2022, https://www.gla.ac.uk/media/Media_967749_smxx.pdf, accessed 7 November 2025.
19 S. Zhou, Z. Dong, H. H. Wang and M. M. Chiu, *Res. Sci. Educ.*, 2025, **55**, 1273–1302, DOI: 10.1007/s11165-024-10216-y.
20 K. Gonzalez, K. Lynch and H. C. Hill, S. Journals, 2025, DOI: DOI: 10.1177/23328584251335302.
21 G. Rizakhojayeva, S. Ramankulov, M. Akeshova, M. Nurizinova, Y. Tuyakov and R. Abdrakhmanov, *Front. Educ.*, 2025, **10**, 1663155, DOI: 10.3389/feduc.2025.1663155.
22 University of the West of Scotland, *University of the West of Scotland*, 2025, https://www.uws.ac.uk, accessed 7 November 2025,.
23 Wentworth Institute of Technology, *Wentworth Institute of Technology*, 2025, https://wit.edu, accessed 7 November 2025.