How Universal Design for Learning Can Support and Retain STEM Learners Across Tertiary Education: A Perspective.

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Abstract.

This critical perspective aims to showcase good practices across STEM disciplines, in particular chemistry and chemical engineering, and how Universal Design for Learning (UDL) can drive and support the inclusion agenda as well as complement university priorities.

With the ever-increasing opportunities and access to university courses/programmes comes diversity in the student population, including in STEM (Science, Technology, Engineering and Mathematics) subjects. This variability includes: gender, international students, mature students, ethnic groups, parents, first generation, neurodiverse learners and students with disabilities. As learner variability comes with such rich diversity and lived experiences this can bring added value to the learning experiences gained from others. However, this diversity and intersectionality can bring many challenges for educators to ensure representation of learners within the content, as well as provision of inclusivity and equity of opportunity. These opportunities apply not only to the provision of access but, more importantly, are key for retention and progression to complete and succeed within a course/programme (Casanova et al. 2023). Consequently, rather than taking a retrofit approach, or focus on differentiation, content needs to be more universal and accessible by assuming from the outset that under-represented learners and those on the margins are in your classroom. So, while planning and designing for a learner-centric inclusive environment, it is necessary to always consider who is advantaged and who is disadvantaged.

This Perspective discusses work of practitioners sharing experiences of embedding inclusion and accessibility within STEM settings. Through this discussion, the authors highlight the benefits of UDL, reflect on some personal experiences and then briefly discuss the future of embedding UDL into STEM subjects.

Keywords: Universal Design for Learning, STEM Education, Tertiary Education, Learner-centred

1. Introduction.

Universal Design for Learning (UDL) provides equitable opportunities for learners to achieve success. UDL is a well-established framework that provides staff with a set of guidelines and concrete suggestions that can be applied across disciplines and educational sectors, that draws on psychological and neuroscientific research in the learning sciences (Rose & Meyer 2006). It is a practical approach to designing inclusive educational practice to embed into learning, teaching and assessment. It can also support learners who are not limited by attributes such as age, ethnicity, socioeconomic status, ability, and gender (Edyburn 2010). Similar to Universal Design (UD) in architecture where the aim is to remove and lower access barriers to physical spaces, UDL works to remove or lower barriers to accessing curriculum content and increase participation in learning to meet students' varying learning needs (Garrad & Nolan 2023). The three UDL principles, introduced by Meyer et al. (2014), consist of multiple means of representation, action and expression, and engagement (CAST, 2018) for designing accessible and inclusive learning environments. The authors of this Perspective see UDL as a philosophy or way of thinking that is learner-centred. It is a reflexive, inclusive approach that requires a mindset shift of design thinking where a one size fits all approach does not work, especially in the current climate of tertiary education.

Across tertiary education there are varying priorities such as widening participation, internationalization, equality, diversity and inclusion (EDI), wellbeing, employability, engagement and student success, partnership, digital accessibility and Education for Sustainable Development (ESD) to support the Sustainable Development Goals (SDGs). UNESCO also monitor progress on EDI in Education, including for Gender equality and the application of universal design (for example, UNESCO Global Education Monitoring Reports 2020, 2023 and 2024). While many institutional priorities are aspirational, some are written into legislation such as digital accessibility (Hamann 2023, Bong & Chen 2021) and both Ireland and Northern Ireland have equality legislation. In Northern Ireland, aims for accessibility/inclusion are contained within university institutional strategy documents (QUB Strategy 2030, UU People, Place and Partnership Strategy) whereas Irish Universities now follow a national charter (ALTITUDE 2024) developed by six national agencies, higher education institutions and the Further Education and Training institutes. The development of the Charter for Universal Design is to be welcomed as it provides external oversight and guidance, and the involvement of national agencies is a recognition of the responsibility and duties of government to higher education; an ethos that was centric to one of the founders of the Queen’s Colleges and the Queen’s University in Ireland (Andrews 1867).

Despite strategy documents, Charter and extensive Case Studies, the connections to learning and teaching are not always obvious for staff, or worse, due to lack of resources and/or leadership, UDL initiatives are not always supported for implementation. It is necessary to do more than merely set goals/policies; there is often a disconnect between these policies and the practicalities involved. It is important that such goals are properly resourced in terms of time and funding; both for professional development activities as well as having the status and salary of teaching and learning (also known as Education and Scholarship) roles equivalent to those of research-related roles (Dransfield et al. 2022). Supporting teaching and learning effectively will lead to improved accessibility and inclusion.

An environment which has adapted and supports UDL has resulted in the publication of an extensive collection of Case Studies published by University College Dublin (UCD) that has numerous examples of application of UDL in many subjects, including Science, Technology, Engineering and Mathematics (STEM) (Padden et al. 2023).

According to UNESCO (2020) UDL “*goes beyond inclusive environments to ensure inclusive teaching*” (p.7) and “*ensures inclusive systems to fulfil every learner’s potential*” (p.40). The focus across tertiary education also focuses on aligning outputs in terms of the United Nations SDGs. While the SDGs have their own shortcomings, there is one of the 17 SDGs that focuses specifically on Quality Education (Goal 4). This goal aims to ensure equal access to all levels of education and vocational training for the vulnerable, which includes persons with disabilities, indigenous peoples, and children in vulnerable situations (UNESCO 2020).

With the ever-increasing diversity of learners and the number of learners who are registering with the disability/wellbeing/accessibility services across the sector (O’Shaughnessy 2021, Quirke et al. 2024), there is more pressure than ever to make changes to our inequitable systems, structures and processes as well as our curriculum. While in terms of access and widening participation, this is certainly seen as positive, it is not a sustainable approach to continue to provide additional resources without systems, structures and teaching and learning processes to also change and become more equitable (Moriña 2017). This is where a framework like UDL can go toward supporting the implementation of inclusive and accessible practices, to support inclusive pedagogies and the increase in learner variability and diversity (Quirke et al. 2024). There is a plethora of literature on the application of UDL for improved accessibility in HE (Cumming & Rose 2022, Garrad & Nolan 2023, Gentile & Budzilowicz 2022). In addition, the learning resources must be effective and accessible because when design considers who is advantaged and disadvantaged, everyone benefits (Wojton et al. 2016).

2. How UDL Can Benefit STEM Learners.

As UDL is a set of flexible principles to promote greater inclusivity in learning, it can be difficult to measure its implementation (Basham et al. 2020) and, as has been seen with other pedagogic findings, results and recommendations are not always widely adapted (DeKorver & Towns 2015).

A Perspective on the application of UDL in STEM is thought to be useful and timely, particularly since many students with disabilities drop out of their STEM programs (Stamp et al. 2014). Additionally, while 22% of the UK public have a declared disability, only 5% of Royal Society of Chemistry (RSC) members self-identified as disabled (Fiss et al. 2023). In 2023 it was reported that disabled scientists are still overlooked (The Forgotten D of DEI 2023). While there is no clear correlation between these statistics and the learning environment, lack of implementation of published, evidence-based practice is a persistent observation. Nature has recently published a collection of articles entitled “*Disability Inclusion in Chemistry*” (Greed et al. 2023). The lack of application of UDL in higher education, including STEM disciplines, creates obstacles in terms of inclusion (Long & Grunert Kowalske 2022). Continuing to promote the UDL Principles, in subject specific fora, will undoubtedly help to improve visibility and utilization.

There are concerns over stagnation (and even decline in some subjects) in the number of applicants seeking to pursue STEM subjects in HE. For example, since 2012, in the UK the total number of applicants for Chemistry has declined while other subjects have seen increased interest (O’Neill 2022). It is interesting to note that the Royal Society has reported that there is an underrepresentation in STEM subjects of both staff and students with disabilities (Frecker 2021). This is despite several resources that have been developed to aid more inclusive practice and teaching students with disabilities, for example from the ACS Committee on Chemists with Disabilities, which are useful resources for a more inclusive approach to teaching Chemistry and similar STEM subjects (Miner et al. 2001, Pagano & Ross 2015, Redden et al. n.d.).

Mainstream education and educators are heavily dependent on visual media. To make the educational environment more inclusive for blind and visually impaired learners it may seem obvious to implement accommodations such as handouts in braille or improved use of succinct verbal descriptors. However, disappointingly, it should not be taken for granted that these basic accommodations will always be available, and so more must be done (Wojton et al. 2016). The application of modern technology such as 3D printers is a good way to improve the sensory experience in a tactile way while the use of microphones can improve the audible sensory experience (Wojton et al. 2016). There are further examples of using tactile teaching tools in STEM subjects such as immunology (Harris et al. 2022). Resources for the periodic table of elements (PTE) have been studied by Fantin et al. (2016), which discusses 3-D printing, molecular modelling kits, and Braille-labelled tactile drawings as ways to study molecules. Braille format textbooks or audio-formatted textbooks are being utilized for the PTE and have been discussed in more detail elsewhere Fantin et al. (2016).

One of the greatest barriers to inclusive practice is the number of misconceptions that persist and a number of those associated with deaf and Hard-of-Hearing (D/HH) students have been summarized in the literature (Long & Grunert Kowalske 2022). Within chemistry this can have implications for health and safety, particularly when educators have little to no prior experience or knowledge of how to support D/HH students in a lab environment (Smith et al. 2016).

Szymanski et al. (2013) reported on the “*Critical Needs of Students who are Deaf or Hard of Hearing*”, and the immediate environment, which includes educators, is the parameter which has the most significant influence on the student experience. Importantly, Long & Grunert Kowalske (2022) summarize creative and effective solutions which have been reported in more detail in the literature, (Smith et al. 2016, Franklin et al. 2018, Lynn et al. 2020).

Braun et al. (2018) is a review where 8 of the 10 authors identify as D/HH and so provide valuable, firsthand testimony, drawing on their own experiences to make recommendations so that STEM courses in higher education can be more inclusive. This also includes a guide for students on steps they should take if suitable and sufficient accommodations are not provided (while this is done from a USA perspective the guidance is still useful more widely as there are equivalent official steps of recourse as ensured by equality legislation). A particular highlight from this review was the strategies for STEM research mentoring; research projects are one of the most engaging aspects of a STEM undergraduate course for all students and it is important that D/HH students have the same opportunities and experience as their peers.

Overall, it is a cornerstone review that reminds all of us involved in education that we must advocate and act on behalf of our students to ensure that they have an inclusive student experience; and one of the most important things we can do is sit directly with students with hearing (or any other) impairment and listen to them as to what interventions will be most effective in supporting their undergraduate journey.

In order to optimize relevance to those studying a subject it is important that there is variety in the role models/experts discussed in lectures. STEM subjects are only beginning to consider this concept. For Chemistry, there are reports of racially inclusive practice for assessment (Bustos-Works et al. 2022, Campbell & Duke 2023) while work on decolonising the curriculum has been explored by Dessent et al. (2022), who provide an excellent guide on how to approach this for Science subjects which includes looking at current high profile scientists, as well as historical ones of non-white ethnicities, and sharing such information with departmental colleagues for inclusion in lectures. Adapting the approach of Dessent et al. (2022) can provide a starting point to a more inclusive experience to students of ethnic minority groups and thereby aid their academic progression.

While accommodations for students with disabilities is important, one needs to go beyond this to ensure inclusive practice that accommodates all underrepresented groups and UDL provides a framework to change the actual learning environment (Fovet et al. 2014); well implemented UDL makes learning accessible to all students (Edyburn 2005), thereby improving everyone’s learning experience.

3. UDL Supporting Flexible Laboratory-based Teaching.

The lack of application of UDL across educational settings also applies to laboratory learning environments (Long & Grunert Kowalske 2022). There is some detailed guidance available for things to consider in terms of improving accessibility of science labs for students with disabilities (Burgstahler 2012, Miner et al. 2001, Pagano & Ross 2015, Redden et al. n.d.). This is important since all students should have the same opportunities to gain and demonstrate knowledge and fully participate in lab lessons. This can be supplemented with advances in accessible science equipment, some of which has been catalogued by the University of Washington (Accessible Science Equipment 2022). Based on the principles of UDL, the recommendations of Burgstahler (2012) include the application of accommodations (e.g. physical access, extra time, individual risk assessments) and goes on to specify further accommodations directly related to certain disabilities and other health complications such as allergies, long term illness and critical incidents.

One of the most informative reports in literature is from authors that identify as having mobility impairments, where insights and recommendations based on firsthand experiences are shared (Blumenkopf et al. 1981). Therein physical modifications to the environment which can allow for full inclusion to work independently were reported. It also reinforces the concept that individuals who face specific challenges and barriers are their "*own expert*" as to what constitutes a suitable working/learning environment. As such, that environment should be planned and designed in consultation with the individual to ensure it meets the needs of achieving independent working. Unfortunately, it is an all-too-common experience that some modifications, including non-STEM specialized ones such as push buttons for doors, will simply not operate when needed due to faults (Brown 2016). There are also important considerations required for accessibility more widely on campus; when rooms are timetabled for teaching these should be accessible for wheelchair users when required and this includes ensuring the route to venues is appropriate (Brown 2016). There is an onus on educators to advocate for their students, but as suggested by Fiss et al. (2023), adopting strategies that benefit all students, such as UDL, will be a key part of a more inclusive environment in the classroom and lab environments.

It is encouraging that a recent Perspective (Seery et al. 2024) reported ten Guiding Principles for learning in the laboratory, some of which accounts for advances in technology. Most pleasing is that the first principle focuses on accessibility regardless of prior knowledge and, more significantly, specifically considers the application of UDL, neurodivergence, students who are blind or have low vision, deaf and hard of hearing students. That perspective by Seery et al. (2024) highlights previous work by Miller & Lang (2016) on the application of UDL in the laboratory settings, which included a workshop for colleagues, including teaching assistants/demonstrators, that introduced UDL with the aim that it would improve interactions with students and reduce student stress since trepidations and anxiety amongst students related to lab classes has been previously reported (Clemons et al. 2019).

4. Personal Reflections on Inclusive Practice in STEM.

Evaluation comments from students summarised in this section were obtained through voluntary and anonymous surveys and ethical standards were upheld by adhering to the guidance of the British Educational Research Association Ethical Guidelines for Educational Research (BERA 2018).

While making accommodations is currently a necessary part of tertiary education, the purpose of UDL is to have an inclusive, learner centric approach where variability is designed for even before an educator meets any learners (Berquist 2017). If we are conditioned to expect diversity, intentional design reduces the proportion of learners who require accommodations although more complex needs may still require further flexible approaches/interventions.

The following reflections (by KM) and interventions came after an institutional guide to inclusive and accessible content that has its foundations in the UDL principles (Galvin 2020) and had the aim of ensuring accessibility of content supports Equality, Diversity and Inclusion (EDI) goals. This is supported by an Accessibility Checker function in the Virtual Learning Environment (VLE), which provides an accessibility score; a quasi-gamification of accessibility that can challenge and inspire colleagues to attempt to improve their own accessibility scores. It should be noted that colleagues will still benefit from guidance by mentors with personal experience with accessibility and UDL. Students respond well to such efforts, and in teaching evaluations, have commented specifically on use of colour coding in complex mathematical solutions as aiding understanding.

KM also reflects on the impact of a Widening Participation activity for Year 13 students from disadvantaged backgrounds (Pathway Opportunity Programme 2024). This is a programme that can be considered as a "*black-box*" intervention, which is considered to be most effective (Younger et al. 2018) as it contains multiple components (online self-paced, day trips and a weeklong residency); students get a broad spectrum of University education including lectures, assessments and lab work. Students can gain a dispensation on entry requirements by successfully completing the programme. The content for this programme embeds and embraces the UN SDGs, and so provides education for societal impact and it was evident from participant evaluations that this was appreciated.

Reflecting further, there is a project-based learning programme giving Year 13 and 14 students from areas of social deprivation the opportunity to feel part of a research community (Institute for Research in Schools (IRIS) 2021, McLaughlin et al. 2024). This is a student-centred approach that promotes active learning (Vidal 1994) and provides the opportunity for students to work on authentic research projects thereby enriching the students' learning (Hadinugrahaningsih et al. 2017). The programme now has Further Education Colleges involved which is particularly pleasing as it has further impact for Widening Participation goals, with now more than 100 students enrolled in the project each year. The feedback from the participant students and their teachers was previously published in McLaughlin et al. (2024), all of which was very positive.

Recently the content and delivery of laboratory practical classes, many of which had retained the same mode of delivery for some time, was reported in more detail elsewhere (Morgan 2023). While UDL and inclusive practice is referenced therein, there was not an extended elaboration in what was already an extensive body of work. Having an instructor (KM) who relatively recently received a postgraduate certificate in Higher Education Teaching and who also avails of additional training on accessibility/UDL as well as several courses accredited by the Staff and Educational Development Association (SEDA), such as Supporting Learning in the Digital Age, have been a driving force in these interventions. This has been complimented with KM's attendance at further courses from the Microsoft Educators Centre and his international recognition as a Microsoft Innovative Educator Expert. All of this has influenced and developed KM as a reflective practitioner who wants to create a more inclusive educational environment and student experience; one fit for the 21st Century.

The introduction of new online pre-lab activities, as is recommended by Clemons et al. (2019), had the intention that well-designed preparatory materials can reduce student anxiety and improve preparedness. This also has the bonus that well designed materials with multiple formats (e.g. e-reader compatible documents and instructional videos with closed captions) and with variable types of assessment (reports, quizzes and posters), and transparency in assessment criteria (using Rubrics), respect the UDL principles. The use of the variability in assessment, including multiple choice quizzes, has been previously reported as a more equitable approach to teaching and learning (Riggs et al. 2020).

After updating the preparatory content a new approach of practical skills assessment within the lab sessions was also implemented, optimizing the opportunity of lower instructor–student ratio to assess students on their practical skills and knowledge in a less formal setting

(Stephenson et al. 2020); providing yet more variability in assessment. A key feature of this iterative improvement process was that it put students at the centre and was co-designed with them, by virtue of acting upon student feedback which has been detailed, alongside the impacts of the interventions, in prior publication (Morgan 2023). The desire for co-design was driven from the knowledge that seeking the views and input of others, particularly those outside of faculty positions (e.g. current students, former students, peers in industry) is important for success since there can be an inherent survivorship bias in curriculum design (O'Neill 2021).

More recently, having learned of underrepresentation of women in chemistry textbooks (Murray et al. 2022) and acknowledging that UDL promotes an inclusive and equitable learning environment that respects the diversity of learners, KM reflected on how representative course content was (Morgan 2024). Realising that all the historical examples/role models in that course content were men, and having been made aware that this is a widespread issue (Murray et al. 2022), KM resolved to update the content to be more representative. This was achieved by adapting the recommendations for decolonizing the curriculum (Dessent et al. 2022) by introducing historical and contemporary women as examples and role models in the field of Catalysis and Catalytic Reactors (Morgan 2024), similar to the strategies reported elsewhere (Dietrich et al. 2022); this intervention was well received by the students. Therefore, by using the principles of UDL to promote inclusivity, it was possible to improve the representation of women in the content using relevant historical and contemporary examples. Moreover, this is a template for how to be more inclusive in our content, reflecting the diverse nature of all our learners regardless of their age, ethnicity, socioeconomic status, ability, and gender.

5. The Future of UDL in STEM: A Summary.

Addy et al. (2021), highlights that the lack of awareness of UDL and the lack of professional development are among the primary obstacles to the practical implementation of inclusive teaching. Embedding UDL is not always an easy concept for STEM educators and they must be supported through professional development and opportunities to collaborate with experts and peers (Ewe & Galvin 2023, Timuș et al. 2023, Galvin & Geron 2021, Addy et al. 2021). Educators must also be given the appropriate space and time to reflect on their practice; one possibility could be the plus one approach (Tobin & Behling 2018) so as not to get overwhelmed with the UDL framework. One important aspect is to develop communities of practice support networks where staff learn from peers and celebrate change, while also having supportive leadership that resource and support professional development.

There are many examples of good inclusive practice in STEM out there that are not widely implemented. One example being additional types of assessment such as oracy (Hennah & Seery 2017) which benefit neurodivergent learners, including those who experience difficulties with reading and writing (typically utilized for assessment). Consideration should be given to how language can be utilized and each student taking turns in a different role within the group to cultivate an equitable learning environment (Hennah & Seery 2022). This approach can also be extended to other STEM formats beyond labs, including design projects for chemical engineering (Chen et al. 2016). Since Chemistry and Chemical Engineering are both tactile subjects, both with a large practical component, this can be a challenging environment for some neurodivergent students due to the potential of sensory overload; this is discussed in great detail in the literature (Flaherty 2022), including ways in which we can support students (Büdy 2021).

When it comes to supporting students with Dyslexia, there are some specific resources in literature such as use of audio books and having a cautious approach to how chemical formulae are used (March 1996, Ragkousis 2000) though it has been previously highlighted (Cídlová et al. 2023) that there are only a small number of results if one searches, for example, the Journal of Chemical Education, for “*Dyslexia*” (only 20 results as of June 2024). More recent literature mentioning Dyslexia tends to include it with other educational needs as part of improving accessibility more widely (for example, Egambaram et al. 2022 and Nardo et al. 2022), which is more in keeping with UDL in any case. Nonetheless, as Hamilton and Petty (2023, p.6) highlight: “*as an alternative to bolt-on accommodations, we propose UDL as a compassionate pedagogy. A UDL approach to curriculum design embeds flexibility and choice in order to make learning accessible to the widest possible range of students*”, and that is especially true for those who are neurodiverse.

UDL is essential for building educators’ competence in digital accessibility (Gilligan 2020 Bong & Chen 2021). According to Galvin & McParland (2023) it is important to note that not all learners engage with learning materials in the same way and that it is important to provide multiple formats and not to over rely on text but also include blog posts, visuals, podcasts, and checklists. Since 2019 with Irish and UK legislation, public sector bodies have never been more aware of its importance, as can be seen from the guidance and resources and staff now focused on digital accessibility during the COVID-19 pandemic. However, with the return of campus-based teaching within tertiary education, there seems to be a shift back to old habits of avoiding recording videos, or not adding captions or alt text on images. Staff cannot claim they are doing UDL if they are not explicitly attempting to embed digital accessibility (O'Shaugnessy 2021). However, if leadership does not identify this on the risk register, or there is no training provided, professional development or guidance, then we are purposely excluding a majority and causing significant barriers for a minority of learners and staff. Digital accessibility needs to be a core part of everyone's role and responsibilities, written into essential job criteria. Digital accessibility should also have a clear pathway for process and complaints, as well as a designated person to collate and guide the university toward best practice; it should also be part of marking schemes and criteria within assessment as a future competency and graduate attributes.

More can be done to promote UDL more generally; and that should be a matter of sharing the extensive work already undertaken by others attempting to provide guidance. Some helpful resources have been developed for better understanding of the Principles through definitions, guidelines and examples (Burgstahler 2020) as well as by demonstrating applications (Burgstahler 2021). By promoting these resources within a STEM context, such as the current work, and by advocating the principles of UDL to peers, it is hoped that there will be more application of UDL. The explicit application of UDL is not widespread across tertiary education, despite quality research having been presented (Schreffler et al. 2019). It is anticipated that the renewed focus on digital education technologies in the aftermath of the pandemic, the possibilities that arose from changes in learning, teaching and assessment practices, as well as the emergence of AI will lead to further implementation since the Schreffler review of 2019.

6. Conclusion.

When one creates the learning environment the first step of UDL is to accept and acknowledge that there will be diversity in terms of the learners (Bowen & Cooper 2022) and that digital accessibility is a core part of that process in terms of learning materials and offering multiple modalities (Bong & Chen 2021; O'Shaugnessy 2021). While STEM disciplines are using more innovative and inclusive teaching methods, it often remains didactic in approach and focuses on traditional methods with a one size fits all approach and not representative of learner diversity and variability. Providing a more flexible and inclusive learning environment for all learners must go beyond accommodations and retrofitting content and processes.

This Perspective has aimed to highlight the role UDL can play in supporting STEM educators to ensure engagement, representation, action and expression. As indicated in the Personal Reflections and the section on the Future of UDL in STEM, there are great opportunities for chemistry and chemical engineering (and other disciplines) to embrace the UDL principles since there are options for variable assessment types, enhancing belonging, improving visibility of underrepresented groups and the presence of tactile learning environments and resources. In fact, it is hoped that the authors have demonstrated throughout this Perspective, many educators internationally and on the island of Ireland are already leading the way.

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