What next for Universal Design for Learning? A systematic literature review of technology in UDL implementations at second level

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What next for Universal Design for Learning? A systematic literature review of technology in UDL implementations at second level

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Abstract

In the last two decades, there has been a global movement towards pedagogies that create more inclusive school environments in order to meet the needs of diverse learners. One such approach is Universal Design for Learning (UDL), which foregrounds the design of flexible and accessible learning experiences for all, regardless of learner characteristics. Technology is a key enabler in this. To date, much of the research on UDL has focused on its impact in higher education, with less evidence available on the use of UDL within second-level education. This systematic literature review of $n=15$ empirical studies selected from a wide-ranging search that returned an initial result of $n=1253$ explores how the affordances of digital technology have been harnessed for UDL enactment at second level. The findings show that, to date, empirical research at second level has focused mostly on the easy wins within the UDL principle of Representation, where educators offer choice about how learners access content. However, there is a clear gap in UDL research on the use of technologies to support the Engagement and Action & Expression principles of UDL, supporting student self-regulation and self-assessment, and on technology-mediated communication and collaboration. The paper highlights the potential for future cross-pollination of research in educational technology with UDL.

KEYWORDS
inclusion, second-level education, technology, Universal Design for Learning

Practitioner Notes

What is already known about this topic

- Universal Design for Learning has been extensively researched in higher education and special education contexts but much less so at K-12, in particular at second level.
- Technology offers many affordances that can provide choice and variation in the learning process, which can be harnessed in a UDL approach.
- The transformative potential of technology in educational contexts was not fully realised pre-COVID.
- The COVID pandemic saw an acceleration in technology adoption for learning, but it remains to be seen whether technology is being deployed to complement or transform existing practices.

What this paper adds

- This paper clearly identifies which affordances of technology are commonly deployed in UDL implementations, particularly noting the provision of choice through multi-media options for Representation and expression.
- There is a clear gap in UDL research on the use of technologies to support self-regulation and self-assessment, (eg, peer, teacher and automated feedback tools) and on technology-mediated communication and collaboration.
- The UDL literature does not address the potential negative impacts of technology within the learning context or the short-lived nature of positive impacts (novelty effect).

Implications for practice and/or policy

- While technology affords great opportunities for choice and Engagement, the design of the learning experience must take priority, availing of technology as needed.
- There are great opportunities for cross-pollination of research at the forefront of educational technology and universal design to address any gaps in technology use in UDL implementations.

INTRODUCTION

The importance of an education system that is inclusive of every learner is widely acknowledged at an international level (UNESCO, 2016). International education policy is increasingly emphasising the need for national education systems to provide inclusive and equitable education for every student (eg, United Nations Convention of the Rights of People with Disabilities; United Nations Conventions on the Rights of the Child; and United Nations

Sustainable Development Goals). While particular attention is often paid to the most vulnerable students, an approach to education that is inclusive is increasingly recognised as beneficial for all pupils (Global Education Monitoring Report Team, 2020). Reflecting these changes in international conventions and national education policies, many systems have begun to explore ways in which innovative pedagogy can promote more inclusive education practice (Evans et al., 2015; Jwad et al., 2022; Takacs & Zhang, 2020). Universal Design for Learning (UDL) is one such framework intended to guide the design and implementation of flexible and supportive learning experiences to meet the needs of all learners (Meyer et al., 2014). UDL emphasises the design of learning experiences to support student Engagement, interaction and learning, whatever their profile (Abell et al., 2011).

Over the past two decades, education systems around the world have begun to use UDL as part of their education policy, curriculum development and teacher education. It is now included in educational policy in the United States (Every Student Succeeds Act (2015) and the Higher Education Opportunity Act (2008)). South Africa has also committed to inclusive education through its education policy and considers UDL a significant element of this process (McKenzie & Dalton, 2020). Australia has begun to apply the principles of UDL within its national curriculum (Evans et al., 2015), and in Ireland, recent curriculum reform has both implicitly and explicitly referred the importance of UDL in teaching and learning (Flood & Banks, 2021). Furthermore, UDL has been noted as an appropriate framework for inclusive education in the Standards for Initial Teacher Education (Teaching Council, 2020) and in further and higher education (Quirke & McCarthy, 2020).

Despite the growing interest in UDL in education policy, there is a gap in the evidence base on the effectiveness of UDL on student outcomes and little understanding of the role technology can play in UDL implementation across different sectors of education (King-Sears et al., 2023). Where research has been undertaken, the main focus has been in higher education and the on aspects of UDL related to the creation of flexible instructional goals, methods, materials and assignments (Smith et al., 2019). Internationally, there are numerous studies relating to the application of UDL in diverse educational systems and at different educational stages (Fovet, 2022; Jwad et al., 2022; Mackey, 2019). Much of the literature and evidence base stems from the United States and other developed countries however, and there is a notable lack of understanding of the scope and potential of UDL in developing countries. Furthermore, not all educational stages have been afforded the same level of focus; second-level education is one of the least studied areas in the field. Although there is a strong literature base promoting the application of UDL, particularly within the field of special education, there is less robust evidence of its effectiveness in improving the learning process for every learner whatever their profile (Ok et al., 2017; Rao et al., 2014).

The situation produced by COVID-19, and the resulting migration of the education system to a virtual or hybrid modality, has resulted in many challenges and opportunities for educators (OECD, 2021a). Several studies have attempted to explore this issue within the context of UDL, with a clear focus on the use of technology as a fundamental axis in a model where accessibility and flexibility are the premises to achieve a better education for all (Basham et al., 2020; Dickinson & Gronseth, 2020; Hu & Huang, 2022; Kilpatrick et al., 2021). There is clearly immense potential for technology to be used to provide options and choice in how to present material, how to express learning and how to engage with education. Furthermore, there is extensive research in the wider education and technology field on the use of technology to support particular aspects of the learning process highlighted in UDL such as self-regulated learning (Willems et al., 2021; Zhu et al., 2016). However, as noted by Edyburn (2010), 'technology is simply the delivery system' (p. 37) and there needs to be intentionality in the design of the intervention and in how technology is integrated within the UDL framework.

The aim of this paper was to examine how and where technology has been deployed to intentionally support UDL implementations in second-level education and to identify areas where technology may offer opportunities for UDL that have not been exploited in the research to date. Using evidence from a systematic literature review (SLR) it focuses on the following research question: *what are the affordances of technology in supporting effective UDL implementations?*

LITERATURE REVIEW

Universal design for learning

Over the past two decades, UDL has become a key pedagogical framework which seeks to address the traditional 'one size fits all' curriculum that exists in many countries (Meyer et al., 2014). UDL addresses inclusive education proactively by assuming a level of student variability in each classroom and building in flexibility and choice in how students engage and take part in the learning process. The framework was designed by the US organisation, CAST, in the 1980s and is based on a set of three principles: multiple means of Engagement where students are provided with multiple ways to engage in learning; multiple means of Representation where students are provided with choice in how they access their learning; and multiple means of action & expression where students are given choice and flexibility in how they demonstrate or share their learning. For a detailed description of the guidelines, checkpoints and each of the principles, see www.cast.org or Flood and Banks (2021).

Despite the growing interest in UDL amongst the education policy community and its gradual emergence in initial teacher education and professional learning (Rao & Okolo, 2018), there is little evidence of the effectiveness of UDL in improving student outcomes and Engagement (Flood & Banks, 2021; Rao et al., 2014). The focus tends to be on the principle of Representation with less focus on Engagement or the student outcomes as a result of the UDL implementation (Capp, 2020; Flood & Banks, 2021).

Affordances of technology in education

Core to the discussion of technology in support of inclusive educational practice is the notion of 'affordance', coined in 1979 by Gibson (1979) and widely used in design, in particular for technology. An affordance is not a characteristic of an object or tool, although the term is often used imprecisely in this way (Norman, 2013); it is a relationship between an object and a person (or more generally, agent) in a particular environment. Therefore, the same object can have different affordances for different people in different environments. If we consider the example of a fountain pen, this tool typically affords writing to an individual. However, in a no-gravity environment, it does not. Similarly, if the person cannot hold the pen in a writing grip for some reason (broken arm, paralysis, etc), the pen may not afford writing, but a speech recognition system may do so. This example serves to highlight that the capabilities of individuals within their environment are as important a consideration as the tool itself when thinking about how to best exploit technology for effective UDL implementations.

The affordances of technology for learning are as diverse as technology itself. Within the framework of sociocultural theory (Vygotsky, 1978), the affordances of technology can be harnessed such that the technology is used as a mediating tool for learning. Technology can be utilised to mediate a wide range of functions: the tasks learners do (eg, text processing, multimedia artefact creation, calculations); how they plan what they will do and how they will learn (eg, planning and scheduling tools); sense-making or the construction of understanding (eg, mindmapping software); how they reflect on learning (eg, journaling tools); and the feedback process to progress learning (eg, peer, teacher or automated feedback systems). In addition, many technological tools incorporate increasingly collaborative potential, which, when combined with learners using social media to support their learning, can also allow technology to mediate communication between learners, between learners and educators and between learners and others in the wider world (Jeong & Hmelo-Silver, 2016). Such communication can be used for a range of purposes, such as Engagement with collaborative tasks, provision of prompts or feedback, provision of emotional support or of an audience for outputs. The range of affordances can be deployed in numerous ways also to support the various dimensions of self-regulated learning (Lai & Gu, 2011; Pintrich, 2004; Yot-Domínguez & Marcelo, 2017), from meta-cognitive regulation using planning tools, to motivation and environmental regulation using computer-mediated communication and collaboration technologies.

However, despite its transformative potential, prior to the COVID-19 pandemic, the impact of digital technologies in education was relatively limited and the potential of technology to transform teaching and learning had not been widely realised (OECD, 2016). Educators typically used technology to complement existing practices (Substitution and Augmentation in Puentedura's (2013) SAMR (substitution, augmentation, modification and redefinition) model) rather than looking to innovate new practices or experiences (Modification and Redefinition in the SAMR model).

While UDL is not dependent on the use of technology, it offers a pedagogical approach within which the affordances of technology to address barriers to learning can be realised (Rose et al., 2012). This paper examines which technologies have been deployed and to what ends in UDL implementation in secondary education contexts. Building on the findings of the SLR, we also aim to identify where technology offers opportunities for teaching and learning that have not yet been harnessed in UDL implementations.

MATERIALS AND METHODS

The goal of this study was to review empirical research that discusses the use of digital technology to support Universal Design for Learning (UDL), with a particular focus on the second-level education sector. This review is one element of a broader project exploring the evidence base for effective UDL implementations at second level. Owing to the objective, transparent and reproducible nature of its data collection and analysis, a Systematic Literature Review (SLR), was identified as the most appropriate approach to achieve this goal. SLRs have become increasingly common within education research, and they are frequently used to support policy decisions (Jones & Gatrell, 2014; Tranfield et al., 2003). The overall review followed the style of a Cochrane systematic review (Higgins & Green, 2011), using EPPI Reviewer software to support the process.[1]

Search procedure

To address the wider project goal to explore the evidence base for UDL at second level, the search procedure was broad and inclusive, drawing results from five relevant databases: Academic Search Complete, Applied Social Sciences Index and Abstracts, ERIC (ProQuest), JSTOR and PsycInfo. Initial search terms included all variations of the terms Universal Design for Learning or UDL in the titles or abstracts of academic papers and reports across these databases (Table 1). The search was conducted on 12 May 2021 and used a very open search strategy in order to return the widest range of papers possible. No

TABLE 1 Terms and syntax of searches.

Database/repository	Terms searched	Limiter	Results
Academic Search Complete	TI universal design for learning OR AB universal design for learning OR TI UDL OR AB UDL	Peer reviewed	415
Applied Social Sciences Index and Abstracts	ab(Universal design for learning) OR ti(Universal design for learning) OR ab(UDL) OR ti(UDL)	Peer reviewed	120
ERIC (ProQuest)	ab(universal design for learning) OR ti(universal design for learning) OR ab(UDL) OR ti(UDL)	Peer reviewed	531
JSTOR	(((ti:(universal design for learning) OR ab:(universal design for learning)) OR ti:(UDL)) OR ab:(UDL))	Papers' research reports	48
PsycInfo	TI universal design for learning OR AB universal design for learning OR TI UDL OR AB UDL	Peer reviewed	139
Duplicates			−430
Total			823

time constraint was placed on the search, so the time period of the study is up to mid-2021. In the title and abstract screening, those including a technology focus were tagged and following the full screening process, those tagged papers were included in this systematic review. In addition to the databases, hand searches were conducted to ensure that no relevant papers were missed. Following this search process, and the removal of duplicates, a total of 823 papers remained for screening.

Screening process

The results of the initial search were imported into EndNote and EPPI Reviewer in preparation for the screening process. In order to ensure consistency across the reviews, the first phase involved a review cross-validation phase with five of the authors screening a sample of 10% of the references by title and abstract screening based on the inclusion criteria in Table 2. Authors paired with at least two others during this phase to compare their results and agree concrete parameters for operationalising the inclusion/exclusion criteria. The remaining papers were then distributed for screening and also coded for the education level in focus. In total, 193 papers met the broad inclusion criteria. Of these, 64 ($n=64$) focused on secondary education settings and were included for full-text screening.

Details of the search and screening process are laid out in the Prisma flowchart in Figure 1. The full-text screening involved three steps:

1. Screening for the general and school-level inclusion criteria (Table 2).
2. Quality appraisal using quality assessment coding tools available within EPPI reviewer to ensure that only the most trustworthy, methodologically sound and pertinent studies were included in the final review.
3. Data extraction of the key characteristics (sample, context, etc) of the included papers.

Full-text screening began with a coding workshop in which the full reviewing team went through the screening and data extraction process for two papers together. In this

TABLE 2 Inclusion/exclusion criteria.

Inclusion criteria	Exclusion criteria
English language	Languages other than English
Focus on an empirical study of a Universal Design for Learning intervention in a real-world setting	Purely theoretical or descriptive account of UDL with no empirical element
Use of qualitative, quantitative or mixed methods methodological approach	Descriptive, theoretical or review papers
School-level inclusion criteria	**School-level exclusion criteria**
Focused on learners in the age range 11–19	Focused on learners under 11 or over 19
Technology used to facilitate UDL	No technology used to facilitate UDL

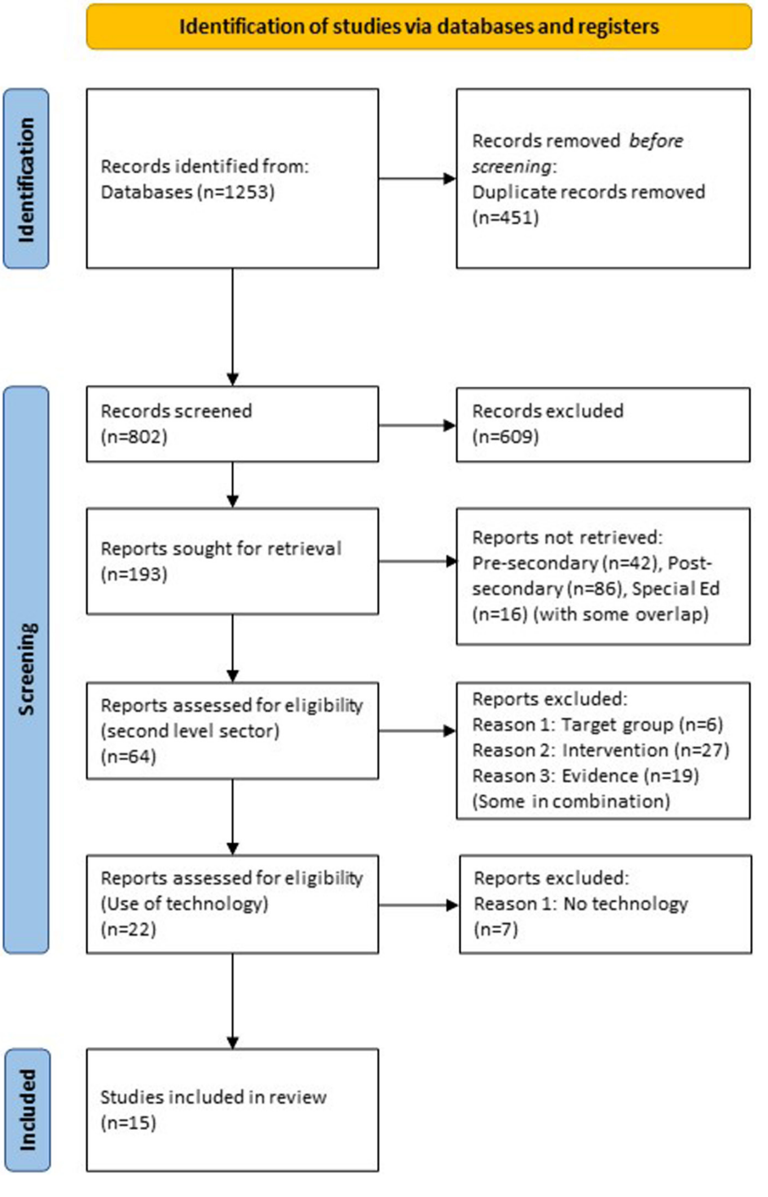

FIGURE 1 Prisma flowchart of systematic review process.

way, the team developed a shared understanding of the codes and the coding process in EPPI reviewer. Subsequent to the coding workshop, the papers were allocated across the seven authors for full-text screening where the reviewers read each paper thoroughly and completed the three screening steps above. The quality assessment followed an approach suggested by Harden and Gough (2012) and used three quality assessment tools available within EPPI Reviewer to explore the quality of evidence in each paper, according to their methodological approach (qualitative, quantitative or mixed methods). However, given the small number of papers identified in the screening process, no papers were excluded on the basis of this appraisal. Following the full-text screening, a total of 22 papers were included for final review, of which 15 ($n=15$) address the research question that is the focus of this paper: *what are the affordances of technology in supporting effective UDL implementations?* The authors acknowledge the small sample size as a limitation in this paper and argue this is a result of keeping the search terms within second-level education and related to technology, where there is scant evidence-based research.

Coding, data extraction

For each paper reviewed, key methodological and outcome information was extracted (see Appendix A), in line with UDL reporting guidelines (Rao et al., 2018). In order to identify the ways in which technology has been used to effectively support implementations of UDL in the second-level education sector, a combination of deductive and inductive coding was used to qualitatively analyse the 15 papers. The papers were imported into the qualitative data analysis tool, NVivo 12,[2] and three codes relating to the three categories of UDL guidelines, were added as pre-defined nodes to direct the analysis. A directed content analysis approach (Hsieh & Shannon, 2005) was taken, combined with a more emergent, open coding within each of these categories, using the constant comparative technique of Strauss and Corbin (2008). Following the process of open coding, a deductive technique was used to match specific UDL checkpoints with the sections of coded text. Examples of this for each UDL Category are provided in Table 3 below.

RESULTS

General information

The study and participant details for the 15 papers reviewed are set out in Appendix A. All of the research reported in the 15 papers is US-based. Twelve of the 15 settings described were mainstream schools (although there was frequently a focus on SEN or diversity within the cohort) and two were in out-of-school settings (Museum: Basham et al. (2010) and Library: Robinson (2017)). One study explored the content of online courses from the Khan Academy.

The scale and scope of the research varied widely between the papers, ranging from a small-scale case study of five participants (Robinson, 2017) to studies involving multiple schools (Ender et al., 2007) and over a thousand students (Marino, 2009; Marino et al., 2010). No particular trends in relation to ethnicity or socio-economic status of the participants were evident. Given the diversity of design, the research methodologies and instruments were also wide ranging, including design-based research (Basham et al., 2010; Daley et al., 2016), documentary analysis (Smith & Harvey, 2014), Quasi-experimental studies

TABLE 3 Steps in coding process.

Paper	Coded segment	1. UDL category	2. Emergent code	3. UDL checkpoints
Daley et al. (2016, p. 127)	'Optional supports included "hint" buttons that provided context-specific guidance'	Multiple Means of Representation	Guidance and Support	2.1, 2.2, 3.1
Hitchcock et al. (2016, p. 18)	'The process of developing their writing slide-by-slide and using the photos on each slide to generate writing in PowerPoint was helpful for those students who were often overwhelmed by the writing process when presented with a blank piece of paper'	Multiple Means of Action & Expression	Multimedia (video-ppt-collage-blog)	5.1, 5.2, 5.3
Marino et al. (2014, p. 91)	'Students could also alter the sound and in some of the games the appearance of their avatar'	Multiple Means of Engagement	Relevance and authenticity	7.1

(Daley et al., 2020; Kennedy et al., 2014; King-Sears & Johnson, 2020) and pre/posttest intervention studies (Hitchcock et al., 2016; Marino, 2009; Marino et al., 2010).

The curriculum areas explored in the research were also diverse, with six studies falling into the category of STEM, three relating to literacy, two focused on history, one on social sciences and the remaining three unspecified. There is a steady increase in studies focusing on technology use in UDL implementations, with three pre-2011 (two papers focused on one study), four between 2011 and 2015 and seven from 2016 to 2020.

What are the affordances of technology in supporting effective UDL implementations?

Overview

Of the 15 papers that reported on the use of technology in their study, eight discussed bespoke technologies/software/interventions that had been designed using the principles of UDL (Basham et al., 2010; Daley et al., 2020; Kennedy et al., 2014; King-Sears & Johnson, 2020; Marino, 2009; Marino et al., 2010, 2014; McMahon et al., 2016). The types of technology discussed include a digital literacy platform (Daley et al., 2020); video games (Marino et al., 2014); multimedia-based instructional modules known as content acquisition podcasts (CAPs) (Kennedy et al., 2014); a *digital backpack* that represents a combination of technologies (hi- and low-tech) that could be adapted according to the project and/or individual needs (Basham et al., 2010); a technology-based astronomy curriculum (Alien Rescue) that uses a virtual space station and a dashboard to support student Engagement with the material (Marino, 2009; Marino et al., 2010); podcasts as an alternative to read-aloud testing accommodations (McMahon et al., 2016); and interactive videos (King-Sears & Johnson, 2020). Three papers used existing technology to support the (re-)design of an intervention to align with UDL: Daley et al. (2016) shared personal usage data from an existing online module in order to support students' help-seeking behaviours; Hitchcock et al. (2016) employed the multimodal features of PowerPoint to support students development of expository writing skills in Science; and Robinson (2017) made use of various assistive technologies to support students in creating a video. The remaining four papers provided a broad overview of the potential for technology, when combined with UDL, to support systemic change (Ender et al., 2007), assessed the UDL alignment of the Khan Academy (Smith & Harvey, 2014), described the use of technology for UDL in very general terms (Abell et al., 2011) or only briefly alluded to UDL (Smith et al., 2020).

The importance of technology in a UDL environment was explicitly noted in 10 of the papers, with some of the authors, such as Ender et al. (2007), considering digital technology an integral component of Universal Design for Learning. While Basham et al. (2010) concur that ‘At the heart of UDL is appropriate technology integration’ (p. 340), they have a more nuanced view of technology within the UDL framework as something that is purposefully designed to meet the needs of the students. The need for careful consideration of the kinds of technology that should be used—‘what works, for whom and under what conditions’ (Edyburn et al., 2017, p. 369)—is echoed the work of Kennedy et al. (2014) and Marino (2009).

The affordances of technology identified in the papers were manifold, but all emphasised supports for personalised learning and choice. The 15 papers were coded according to whether the technology they discussed focused on Multiple Means of Representation (the ‘what’ of learning, $n=13$), Multiple Means of Action/Expression (the ‘how’ of learning, $n=11$) and/or Multiple Means of Engagement (the ‘why’ of learning, $n=11$) (Table 4). The primary focus was on using technology for Representation (multiple references across 13 papers) with less emphasis on both Engagement and Action & Expression. Eight studies used the affordances of technology to address all three UDL pillars: multiple means of Representation, Action/Expression and Engagement. However, across all the papers, the primary focus was on at most two of these categories. The affordances of technology to support each of these categories are illustrated in Table 4 below.

As regards the UDL checkpoints within each principle, fewer checkpoints associated with Engagement were identified within the papers included in this review. Indeed, exploration of the number of CAST checkpoints within each of the categories shows that: for Representation, nine of the 12 checkpoints were noted; for Action/Expression, five of the possible nine were identified; and for Engagement, only three of the 10 associated checkpoints were addressed (Table 5).

Technology for Representation

The most prevalent method of using the affordances of technology to support learners in relation to the ‘what’ of learning related to the provision of support and guidance. This was most frequently operationalised as additional information, hints or tips that the student could choose to access (CAST checkpoints 2.1, 2.2 and 3.1) (Abell et al., 2011; Basham et al., 2010; Daley et al., 2016; Marino, 2009; Marino et al., 2010, 2014; McMahon et al., 2016), but also included built-in, explicit support through the use of multimedia (Hitchcock et al., 2016), and the use of feedback by way of system analytics to support help-seeking behaviour (CAST checkpoint 3.3) (Daley et al., 2016).

The use of multimedia to represent information in a variety of ways (CAST checkpoints 1.2, 1.3 and 2.5) was common across six papers, ranging from podcasts that included visual and textual information (Kennedy et al., 2014) to a two-layered interface that provides one set of common tools (access to additional information, glossary, etc) and tools that vary according to the specific content under examination (Marino, 2009; Marino et al., 2010).

TABLE 4 Technology affordances for learning in UDL implementations.

Technology for Engagement ($n=11$)	Technology for Representation ($n=13$)	Technology for Action & Expression ($n=11$)
Choice of Action, for example choice of response to open-ended questions using text, audio or drawing (Daley et al., 2016)	**Audio**, for example facilitation of listening to text such as titles, papers or written comments (Daley et al., 2020)	**Multimedia**, for example students were encouraged to use video, presentation software such as PowerPoint, collage or blog posts to represent their learning (Hitchcock et al., 2016; Robinson, 2017)
Choice of Content, for example use of a 'dashboard' to facilitate self-directed learning (Daley et al., 2020)	**Video and video games**, for example use of video resources for research (Robinson, 2017), or provision of opportunities to interact with material (Marino et al., 2014)	**Supports and starters**, for example scaffolded problems (King-Sears and Johnson, 2020; McMahon et al., 2016), templates, sentence starters and guidance (Dayley et al., 2020; Marino et al., 2014) supported students to demonstrate what they had learned
Relevance and authenticity, for example use of a multimedia environment to support personal creativity in project work (Hitchcock et al., 2016)	**Multimedia**, for example content acquisition podcasts create meaningful representations of content through the use of images, audio and occasional on-screen text to help facilitate learning (Kennedy et al., 2014)	
Scaffolding and support, for example audio, textual and/or visual explanations of scientific terms that can be accessed by clicking on the word on screen (Marino, 2009)	**Text to speech**, for example Daley et al. (2020), included a set of controls for listening to the on-screen content; Hitchcock et al. (2016) encouraged students to record their own writing and listen back to it; and McMahon et al. (2016) used podcasts for read-aloud test-administration	
	Translation, for example Spanish translations of text in Dayley et al. (2020)	
	Customisation of text size, for example text enlargement in Abell et al. (2011)	
	Guidance and support, for example 'hint' buttons for the provision of context-specific guidance (Dayley et al., 2016)	

The different colour shading reflects the three principals of the UDL framework (https://udlguidelines.cast.org/).

TABLE 5 Checkpoints identified in the review.

Provide multiple means of engagement	Provide multiple means of Representation	Provide multiple means of Action & Expression
Provide options for recruiting interest	**Provide options for perception**	**Provide options for Physical Action**
Optimise individual choice and autonomy (**checkpoint 7.1**) ✓	Offer ways of customising the display of information (**checkpoint 1.1**) ✓	Vary the methods for response and navigation (checkpoint 4.1)
Optimise relevance, value and authenticity (**checkpoint 7.2**) ✓	Offer alternatives for auditory information (**checkpoint 1.2**) ✓	Optimise access to tools and assistive technologies (checkpoint 4.2)
Minimise threats and distractions (checkpoint 7.3)	Offer alternatives for visual information (**checkpoint 1.3**) ✓	
Provide options for Sustaining Effort & Persistence (guideline 8)	**Provide options for Language & Symbols (guideline 2)**	**Provide options for Expression & Communication (guideline 5)**
Heighten salience of goals and objectives (checkpoint 8.1)	Clarify vocabulary and symbols (**checkpoint 2.1**) ✓	Use multiple media for communication (**checkpoint 5.1**) ✓
Vary demands and resources to optimise challenge (checkpoint 8.2)	Clarify syntax and structure (**checkpoint 2.2**) ✓	Use multiple tools for construction and composition (**checkpoint 5.2**) ✓
Foster collaboration and community (checkpoint 8.3)	Support decoding of text, mathematical notation and symbols (checkpoint 2.3)	Build fluencies with graduated levels of support for practice and performance (**checkpoint 5.3**) ✓
Increase mastery-oriented feedback (checkpoint 8.4)	Promote understanding across languages (**checkpoint 2.4**) ✓	
	Illustrate through multiple media (**checkpoint 2.5**) ✓	
Provide options for Self-regulation (guideline 9)	**Provide options for Comprehension (guideline 3)**	**Provide options for Executive Functions (guideline 6)**

TABLE 5 (Continued)

Provide multiple means of engagement	Provide multiple means of Representation	Provide multiple means of Action & Expression
Promote expectations and beliefs that optimise motivation (checkpoint 9.1)	Activate or supply background knowledge (**checkpoint 3.1**) ✓	Guide appropriate goal-setting (checkpoint 6.1)
Facilitate personal coping skills and strategies (checkpoint 9.2)	Highlight patterns, critical features, big ideas and relationships (checkpoint 3.2)	Support planning and strategy development (**checkpoint 6.2**) ✓
Develop self-assessment and reflection (**checkpoint 9.3**) ✓	Guide information processing and visualisation (**checkpoint 3.3**) ✓	Facilitate managing information and resources (**checkpoint 6.3**) ✓
	Maximise transfer and generalisation (checkpoint 3.4)	Enhance capacity for monitoring progress (checkpoint 6.4)

The different colour shading reflects the three principals of the UDL framework (https://udlguidelines.cast.org/).

The potential of incorporating video and/or audio as alternatives to the traditional print Representation of content was widely discussed (Abell et al., 2011; Basham et al., 2010; Daley et al., 2016; King-Sears & Johnson, 2020; Marino, 2009; Robinson, 2017), with text-to-speech functionality specifically addressed by Daley et al. (2020), Hitchcock et al. (2016), Marino et al. (2014) and McMahon et al. (2016). Other affordances of technology that were classified under multiple means of Representation related to the ability to adapt the size of text/visuals (Abell et al., 2011) and embedded translation (Daley et al., 2020) (CAST checkpoints 1.1 and 2.4).

Technology for Engagement

According to Daley et al. (2016), 'in the UDL framework the approach to learner variability hinges on providing options and supporting learners to make their own choices about use of those options' (p. 126). In relation to multiple means of Engagement, this analysis found good evidence of technology being used to offer choice and autonomy (CAST checkpoint 7.1) to students in terms of the content that they accessed and the actions that they could take. In many cases, this overlapped with how technology supported *multiple means of Representation*, in that the students could choose whether or not to engage with particular content for support and guidance (Daley et al., 2016, 2020; Marino, 2009; Marino et al., 2010; Robinson, 2017). Similarly, choice of action overlapped significantly with *multiple means of Action/Expression*, in that the use of technology afforded students greater choice in how they could express their learning (Daley et al., 2016, 2020; Hitchcock et al., 2016; Marino et al., 2014; Robinson, 2017; Smith et al., 2020). Unsurprisingly, the provision of technological tools that support students' Engagement with material in ways that suit their strengths and address their needs tended to lead to higher levels of Engagement and confidence (Hitchcock et al., 2016).

Six of the papers reviewed indicated that when students were provided with options relating to the supports, scaffolds and feedback they could engage with, and how they might choose to do so, it could lead to higher levels of comprehension, self-assessment and reflection (CAST checkpoint 9.3) (Daley et al., 2016, 2020; Hitchcock et al., 2016; King-Sears & Johnson, 2020; Marino, 2009; McMahon et al., 2016).

The use of technology to increase the relevance and authenticity (CAST Checkpoint 7.2) of the activities was noted in two papers. Hitchcock et al. (2016) highlighted that the choice afforded by the multimedia nature of the activity gave students the opportunity to 'integrate their own personalities into the projects' (p. 20), and Marino et al. (2014) indicate that the opportunities for personalisation within the game, as well as the nature of the gameplay, led to heightened levels of connection and relevance for the students.

Technology for Action/Expression

The Principle of Action & Expression (the 'how' of learning) was referenced least in the review papers. Eight of the papers commented on how technology could offer multiple modalities for students to represent their learning (CAST Checkpoints 5.1, 5.2 and 5.3). Options discussed included digital collages, video clips, audio, text, drawing or various combinations thereof within a multimedia environment (Abell et al., 2011; Basham et al., 2010; Daley et al., 2016, 2020; Hitchcock et al., 2016; Marino, 2009; Robinson, 2017; Smith et al., 2020).

In addition to offering students diverse ways to express their learning, technology was also utilised to offer support for action & expression through various supports and scaffolding (CAST Checkpoints 5.3, 6.2 and 6.3). For example, Daley et al. (2020) refer to the optional use of 'sentence starters' (p. 283) to support students who want to type their responses; King-Sears and Johnson (2020) and Marino et al. (2014) refer to the use of scaffolding for problems, with levels of support adapted according to the students' level of proficiency; and McMahon et al. (2016) discuss how the use of podcast read-aloud encourages planning and strategy development by giving students the option to decide the order in which they answer questions.

DISCUSSION

This paper highlights the growing research interest in the use of technology to support UDL implementations, with an increasing number of empirical research papers published in recent years. While technology is not considered a requirement for UDL (Rose et al., 2012); the research findings from this review suggest that the affordances of technology can make some aspects of teaching and learning considerably more inclusive for all learners. In particular, the research illustrates how the multi-modal nature of technology allows for greater choice across the UDL guidelines and, where this choice aspect is enhanced, how greater student Engagement can be achieved.

The authors acknowledge several limitations to an SLR as a method to explore phenomenon in education. As mentioned above, the sample size of the papers selected is small as a result of the strict search criteria used, particularly, the narrowing of the focus to second-level education and interventions where technology was used. Although a limitation, this narrow focus allowed for the in-depth understand of the literature available and allowed the authors to identify gaps.

Analysis of the papers included in this review demonstrates the importance and value of technology in the implementation of UDL at second level. The papers reviewed show how the affordances of technology have been widely used to offer choice and to inject more fun and authenticity into the learning, most commonly reflecting the UDL principle of Representation. Considerations of more student-centred activities such as collaboration, managing focus in relation to learning goals, and developing student behaviours and coping skills have been less well addressed. This reflects a tendency within the research into UDL at second level, on aspects of the environment that are within the control of the educator (flexible instructional goals, methods, materials, etc) (Smith et al., 2019), which may be attributable to the fact that many education systems are only at the beginning of their UDL journey.

In addition, few of the papers acknowledge the need to consider student capacity and skill set when engaging with technology in UDL (Basham et al., 2010; Kennedy et al., 2014; Marino, 2009; OECD, 2016). This demonstrates a clear shortfall in the research which gives little acknowledgement of the key role of learner capabilities in context when using technology to mediate learning (Gibson, 1979; Norman, 2013; Vygotsky, 1978). The widespread use of diverse media to provide multiple means of Representation is reflective of this, indicating a base assumption that more choice is better. There is little consideration of the increase in cognitive load (Sweller, 1988) imposed by multiple means of Representation within the papers. Although multimedia can enhance the learning where the environment is well-designed, if it is not integrated and scaffolded appropriately, it can place an additional cognitive load on learners which can be distracting and detrimental to learning (Jamet et al., 2020; Mayer, 2014). Clearly, when providing choice, instructional designers and educators must be conscious to follow design principles that support learners to avail of the options most appropriate to them.

One way of addressing these issues could be through explicit emphasis on some of the UDL checkpoints that can provide the constraints to manage cognitive load. This might include a focus on, for example checkpoint 6.3 within Action & Expression—facilitate managing information and resources, or checkpoint 7.3 in Engagement—minimise threats and distractions. Within the category of Representation, an increased focus on the Comprehension checkpoints such as 'highlight patterns, critical features, big ideas, and relationships' (checkpoint 3.2), should also help to address issues around cognitive load, without simply providing more options to learners.

Another critique of the research reviewed relates to the lack of emphasis on the UDL principle of Engagement. It is particularly notable that none of the papers explore the role of technology in fostering collaboration and community between learners (checkpoint 8.3). This is somewhat surprising given that the social dimension of motivation (Ryan & Deci, 2020) and learning (Vygotsky, 1986) have become increasingly well theorised and explored in recent times. The explosion in social media and collaborative technologies over recent years provides a wealth of tools that offer learners the affordance of connection and co-presence with others during the learning process, to enhance motivation and provide support in a range of ways (Allen et al., 2014; Blaschke, 2014; Bulu, 2012). More recently, during the COVID-19 school closures, digital technologies were essential in maintaining connectedness and Engagement with learners in online schooling (Bray et al., 2021). Even in a face-to-face setting, collaborative technologies can be used constructively to support learning (Nussbaum et al., 2009; Wang et al., 2021). It is important to note, however, that the use of social media in an educational setting with adolescents is complex. Although there can be positive outcomes, such as providing support and meaningful connection with peers, significant negative associations from cyberbullying, negative self-image and sleep deprivation to anxiety and depression have also been identified (Viner et al., 2019). The evidence base for what constitutes appropriate social media use is growing and should be addressed intentionally before using such platforms within a UDL context (Van Den Beemt et al., 2020).

A further gap in the literature identified through this review relates to the development of student self-regulation and sustaining effort and persistence (checkpoints 8 and 9). Although the UDL Engagement principle aims to foster these skills, they are not addressed explicitly in the papers examined. These skills develop when students are well scaffolded and supported (Boekaerts & Cascallar, 2006; Hawe & Dixon, 2017) and are given the opportunity for reflection (Masui & De Corte, 2005)—aspects of learning for which technology has been used for some time (Lin et al., 1999). Learning management systems (LMSs) can be used to offer formalised mechanisms for clarifying and refining goals of learning and providing feedback (checkpoints 6.1, 6.4, 8.1, 8.4 and 9.3), for example through the use of rubrics (Andrade, 2007). The tools to support feedback are well established for facilitating teacher and peer feedback. Emergent technologies that make use of artificial intelligence and natural language processing to generate automated feedback, or more comprehensive Intelligent Tutoring Systems are less well advanced but may, in the future, offer learners timely and focused feedback to maintain Engagement and focus on their learning goals (OECD, 2021b). Indeed, as noted in the literature review, technology offers learners many affordances to develop self-regulated learning capacities, but it also often demands that learners become more self-regulated to avail of the opportunities for learning through technology, in particular in online and blended learning contexts. The UDL community needs to harness the existing evidence base on technologies to support self-regulated learning (Yot-Domínguez & Marcelo, 2017).

LIMITATIONS AND FURTHER RESEARCH

All research is subject to limitations, and despite its rigorous approach, systematic literature review is no exception. While every effort was made to ensure that all relevant papers were identified through the use of an intentionally broad search strategy across five databases, two of which are multidisciplinary (Academic Search Complete and JSTOR), it is possible that expanding that to other databases may have exposed further relevant results.

Publication bias is an acknowledged limitation of systematic reviews, with published research more likely to report positive results, which can limit the generalisability of the study. Similarly, the very nature of a review of this kind limits the data to extant research that does not necessarily reflect the situation in the real world.

In addition, the scope of this particular review is quite narrow, in that it focuses solely on the affordances of technology in supporting UDL implementations and does not discuss the learning effectiveness or learning experiences of participants. However, this is part of a broader, cross-sectoral study. A related paper, currently under review, focuses explicitly on the learning outcomes and effectiveness of UDL in formal educational settings (Devitt et al., 2023).

CONCLUSION

This paper reports on the findings of a systematic literature review of 15 papers that consider the affordances of technology in the implementation of UDL at second level. The review identified key areas in which technology is being used to support UDL implementations. The findings show that, to date, empirical research at second level has focused mostly on technology and UDL implementations that prioritise the teacher perspective on UDL such as the ways in which choice is offered, or how they enable students to access content. This has resulted in significant research focus within the UDL principle of Representation, with considerably less emphasis on the other two principles: Engagement and Action & Expression. Within this context, there is a notable leaning towards multimedia tools, which can provide an easy win, allowing educators to provide choice in how content is communicated and accessed. However, it is essential to be cognisant of the fact that technology can have positive and negative impacts. In future work, researchers should consider the impact of technology integration in relation to increased cognitive load, the effects of multi-tasking and distractions as well as the potential novelty effect of technology, which suggests that the positive impact of new media on learning may decrease over time (Clark, 1983).

The findings of this review not only demonstrate the significant role of technology in UDL implementations but also identify gaps in particular domains of teaching and learning. In particular, this research suggests the need to extend the focus of technology in UDL implementations to include supports for students' self-regulation (Engagement) and self-assessment (Action & Expression). The successful enactment of all three principles of UDL will require moving away from the relatively easy wins of providing learners with choice in how they engage with content and showcase their learning. While emerging technologies using artificial intelligence and machine learning, such as automated assessment and intelligent tutoring systems, have potential to provide support for learners within the principles of Engagement and Action & Expression, the quality and effectiveness of these systems still require evaluation.

UDL considerations are hugely important for the development of new systems to ensure they are equitable by design (Miao et al., 2021). However, in addition to the design of the technology itself, it is important to bear in mind that tools have certain affordances in the context of specific environments and learners. Therefore, it is imperative that the design of an intervention, and how technology is integrated within it, is intentionally situated withing the UDL framework. This clearly indicates that there are significant opportunities in future empirical research for cross-pollination between UDL and educational technology. Future research could, for example, map the impact of educational technology within a UDL context to the extent to which students self-regulate their learning. Given the potential benefits of this, this paper suggests the need for large-scale, quantitative or mixed-methods research studies on the integration of UDL in second-level educational contexts.

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CONFLICT OF INTEREST STATEMENT

None of the authors has a conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this paper as no datasets were generated or analysed during the current study.

ETHICS STATEMENT

Given the non-empirical nature of this work (SLR), it was not bound by the ethical considerations associated with empirical studies involving human participants, such as voluntary participation, informed consent, anonymity, confidentiality, potential for harm and results communication. The work was, however, bound by the ethical responsibility to conduct rigorous, academic research.

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ENDNOTES

[1] https://eppi.ioe.ac.uk/CMS/Default.aspx?alias=eppi.ioe.ac.uk/cms/er4

[2] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

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APPENDIX A

Paper overviews

N°	Year	Authors	Setting	Sample	Participant information (students)	Study duration	Curriculum area	Research methodology	Research instruments
1.	2011	Abell et al. (2011)	USA	867	*Age range*: 8–18 *No. with low SES*: not specified *No. with AEN*: not specified *Gender*: not specified *Ethnicity*: not specified	N/A	Diverse	Survey	Revised Individualised Classroom Environment Questionnaire (ICEQ-R)
2.	2010	Basham et al. (2010)	USA	35	*Age range*: Upper high school *No. with low SES*: not specified *No. with AEN*: 1 *Gender*: 13 male, 22 female *Ethnicity*: majority African American	4–5 h each cycle	Social sciences	Design-based research (3 cycles)	All cycles: Participant observations, video-recorded observations, field notes, student-generated artefacts. Cycles 2 and 3: student surveys and interviews
3.	2016	Daley et al. (2016)	USA	126	*Age range*: Grade 6 *No. with low SES*: School B: 63% *No. with AEN*: 12 *Gender*: 52 male, 74 female *Ethnicity*: *School A*: 82% white, 15% Asian American. *School B*: 98% African American	3–5 lessons	Science	Design-based research (1 cycle)	Electronic event usage log written student inquiry questionnaires
4.	2020	Daley et al. (2020)	USA	315	*Age range*: Grades 6–8 *No. with low SES*: 78% *No. with AEN*: All, with 56% SEN *Gender*: 63% male, 37% female *Ethnicity*: Hispanic or Latino: 36%, White: 31%, Black or African American: 26%, Asian or Pacific Islander: 2%, multiracial: 4%	1 year (1 h per week)	Literacy: Reading	Quantitative Quasi-experimental, pre–posttest design	Reading comprehension pre-/posttests Digital usage log in UDIO tool

APPENDIX (Continued)

N°	Year	Authors	Setting	Sample	Participant information (students)	Study duration	Curriculum area	Research methodology	Research instruments
5.	2007	Ender et al. (2007)	USA	0	*Age range*: not specified *No. with low SES*: not specified *No. with AEN*: not specified *Gender*: not specified *Ethnicity*: not specified	3 years	Diverse	Not specified	Different evaluation instruments used in different schools. School level: Staff and Student survey and interviews; classroom observations; reports; school, teacher and student products. Project Level: (a) Individualized Classroom Environment Questionnaire (ICEQ); (b) CATS scores and NCLB Adequate Yearly Progress (AYP) reports; and (c) monthly and year-end reports
6.	2016	Hitchcock et al. (2016)	USA	46	*Age range*: Grades 5–8 *No. with low SES*: not specified *No. with AEN*: Classroom A: 11%, Classroom B: 5% *Gender*: not specified *Ethnicity*: Hawaiian/part-Hawaiian: 70–85%	12 weeks	Literacy: Writing	Mixed-methods: within-person pre/postintervention comparison and naturalistic case study	Quant: pre-/postwriting tests: Woodcock Johnson III, CBM Rubric Teacher and Student evaluations Qual: teacher/student surveys and focus groups
7.	2014	Kennedy et al. (2014)	USA	141	*Age range*: Grade 10 *No. with low SES*: 83% *No. with AEN*: 32 *Gender*: 76% male, 24% female *Ethnicity*: 63.3% African American, 26.7% Hispanic, 10% Caucasian	8 weeks	History	Quasi-experimental study	Pre-test and posttest scores curriculum-based measures- probes of terms/historical figures and definitions

APPENDIX (Continued)

N°	Year	Authors	Setting	Sample	Participant information (students)	Study duration	Curriculum area	Research methodology	Research instruments
8.	2020	King-Sears and Johnson (2020)	USA	44	*Age range*: High school *No. with low SES*: 21 *No. with AEN*: 16 (Study 1: 10; Study 2: 6) *Gender*: 24 male, 18 female *Ethnicity*: 5 White, 13 African American, 22 9Hispanic, 2 Multiracial	2 sessions	Chemistry	Two quasi-experimental studies	Pre- and posttests and social validity questionnaire
9.	2009	Marino (2009)	USA	1153	*Age range*: Middle school: grades 6–8 *No. with low SES*: not specified *No. with AEN*: 126 with severe reading difficulties, 205 poor readers *Gender*: 50% male, 50% female *Ethnicity*: 91% White, 5% Asian, 3% Hispanic, 1% African American	4 weeks	Science—astrophysics	Pre/posttest Intervention Study (no control group)	1. Pre-/posttest of scientific concepts, processes and vocabulary (paper-and-pencil 25-item multiple-choice) 2. Six open-ended paper-and-pencil solutions forms 3. Degrees of Reading Power (DRP). 4. Tool Use Log. 5. Observations
10.	2010	Marino et al. (2010)	USA	1153	*Age range*: 10–14 *No. with low SES*: not specified *No. with AEN*: ~11.5% (based on average across participants from the 3 schools) *Gender*: 50% male, 50% female *Ethnicity*: 91% White, 5% Asian, 3% Hispanic, 1% African American	4 weeks	Science—astrophysics	Pre/posttest Intervention Study (no control group)	1. Pre-/posttest of scientific concepts, processes and vocabulary (paper-and-pencil 25-item multiple-choice) 2. Six open-ended paper-and-pencil solutions forms 3. Degrees of Reading Power (DRP). 4. Tool Use Log. 5. Observations
11.	2014	Marino et al. (2014)	USA	341	*Age range*: 10–14 *No. with low SES*: 56% *No. with AEN*: 57 *Gender*: 51% male, 49% female *Ethnicity*: 87% White	1 year	Science—pathogens	Mixed-methods design. ABAB intervention model	Paper-and-pencil pre-/posttest, data collected through video game play, student postintervention focus group interviews

APPENDIX (Continued)

N°	Year	Authors	Setting	Sample	Participant information (students)	Study duration	Curriculum area	Research methodology	Research instruments
12.	2016	McMahon et al. (2016)	USA	47	*Age range*: Grade 6 *No. with low SES*: ~97.4% *No. with AEN*: 47 *Gender*: 57.4% male, 42.6% female *Ethnicity*: 76.6% African American, 17% Caucasian, 4.3% Hispanic, 2.1% Native American		Science (assessment context)	Generalised Latin squares comparative study—differences within and between groups	Pre-/postcontrol/ experimental test scores
13.	2017	Robinson (2017)	USA	5	*Age range*: Middle school *No. with low SES*: not specified *No. with AEN*: 5 *Gender*: not specified *Ethnicity*: not specified	3 months	History (in library setting)	Case study	No explicit data collection
14.	2014	Smith and Harvey (2014)	USA	0	*Age range*: N/A *No. with low SES*: N/A *No. with AEN*: N/A *Gender*: N/A *Ethnicity*: N/A	N/A	Mathematics, Science, World History	Documentary analysis	UDL Scan Tool
15.	2020	Smith et al. (2020)	USA	730	*Age range*: Grade 6 *No. with low SES*: 46% *No. with AEN*: 75 *Gender*: 49% male, 51% female *Ethnicity*: 57% white, 11% African American, 25% Hispanic and 7% ‘other’	1 year	Literacy: Writing		WRITE Progress Monitoring tool (WPM)