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Business as Usual or Digital Mechanisms for Change?

What Student DLOs Reveal About Doing Mathematics

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ABSTRACT

Mathematics classrooms have a long history of what has been termed 'unidimensional' character: a proclivity for student practice routines and teachers as experts and keepers of knowledge. This study investigates affordances of student-created digital learning objects (SC-DLOs) as transformative, design-for-learning practices in the hands of students. Historical distinctions are drawn between digital learning objects (DLOs) and digital learning artefacts (DLAs) primarily for teacher assessment of student learning. SC-DLOs are conceived as students' design for learning for the peer learning community. Hence, SC-DLOs have additional and different learning potential that aligns with 21st century skill development. A corpus of mathematics SC-DLOs (n=155) were analysed from learner blogs (Year 7-8) in a 1:1 digital initiative in New Zealand. A mixed-methods approach was used to investigate features of students' multimodal design for learning. A framework of implications informs and problematises understandings of transformative digital creation by students in mathematics.

KEYWORDS

1:1 Learning, Design-for-Learning, Digital Learning Object, Knowledge Building, Mathematics, Student Multimodal Artefacts, Student-Created DLO

INTRODUCTION

Creating, sustaining and scaling change in classroom pedagogy is a recognised and on-going challenge to learning innovation and outcomes improvement (Jesson, McNaughton & Wilson, 2015). In the subject area of mathematics, researchers and commentators continue to highlight barriers to change in mathematics teaching from prevailing attitudes and beliefs about active student participation in mathematical discourse (Boaler & Sengupta-Irving, 2016), problem solving investigation (Bailey, 2017) and collective knowledge building (Hunter, 2005, 2008). Mathematics classrooms have a long history of what Boaler (2008) terms 'unidimensional' character; where procedural routines dominate and the teacher is keeper and expert of knowledge (Soto, 2015). Digital learning environments (DLEs) may offer creative mechanisms for 'disruption' by providing opportunities for student design of conceptual digital objects and collaboration. Student-created digital learning objects (SC-DLOs) are conceived as going beyond skill-and-drill such as apps for practice and feedback because SC-DLO practices can position students as both designers and sharers of knowledge (Cope & Kalantzis, 2017).

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The reasons are at least two fold: (1) SC-DLOs are more than digital artefacts (or products) of the students' learning because they involve making *design-for-learning* decisions (Bezemer & Kress, 2008) by the student to enhance learning for others; (2) By adopting the role of 'instructor', student-designers potentially deepen learning by reflecting on how best to explicate knowledge for others by combining digital modalities (Kress & van Leeuwen, 2006). Design for learning by students is in line with developing desirable 21st century competencies and futures (Lai & Viering, 2012).

By analysing a corpus of students' mathematics SC-DLOs (n=155), we will argue for a qualitative difference between student-created digital learning artefacts (SC-DLAs) (e.g. worked example of an algorithm using mathematical notation) and digital learning objects (SC-DLOs) (e.g. screencast recording of a student explaining how to solve an algorithm for an online audience as a 'rewindable' resource). Therefore, a blogged screenshot of student *Mathletics*[1] progress, or photograph of groups using manipulatives to count are not considered SC-DLOs, as the artefacts represent no obvious instructional intent on the part of the designer. On the other hand, a screencast explanation of how to balance an equation is instructionally explicit in both the choice of medium (screencast demonstration) combined with verbal guidance.

Producing SC-DLOs requires access to media such as slide presentations, screencast, video, podcast and animation to afford design decisions with the full complement of multimodal resources (e.g. combinations of image, audio, writing, movement, gesture and spatial modes). Historically, DLO design by educational resource providers have been informed by taxonomies for enhancing learning potential (Churchill, 2007). Mayer's (2014) model of twelve principles of multimedia learning has had considerable impact on the field of multimedia design for learning by emphasising: (a) visual-verbal complementarity (b) human personalisation (e.g., use of voiceover), and (c) reducing extraneous cognitive load such as minimising distraction (e.g., unnecessary animation). Students in K-12 settings are unlikely to be aware of the formal principles of design for learning in everyday subject learning, but are likely to draw on age-related experiences of digital texts when design-for-learning awareness is emphasised.

BACKGROUND

There is a growing body of research featuring teachers' instructional use of DLOs (e.g. from educational resource providers), but only emerging research in SC-DLOs created by students. A search of peer-reviewed studies in prominent academic journals returned only four articles describing SC-DLOs in mathematics. Three involved use of screencasts (Croft, Duah & Loch, 2013; Shafer, 2010; Soto, 2015) with one use of podcast (Adams & Blair, 2014). The single primary school study included a large sample of SC-DLOs (n=47) (Soto, 2015) where students were asked to imagine creating screencasts for their peers. Therefore, the present study contributes further to SC-DLO scholarship by analysing the largest study sample to date, detailing the multimodal features and the implications of findings related to performative effects (where students positioned to teach others). This study is also situated within 1:1[2] school settings where students arguably have considerably more agency and day-to-day experience using digital devices for learning, including a potentially wider pool of SC- DLO forms they can create (e.g. podcast, animation, presentation). In the interests of exploring ways SC-DLOs may (or may not) contribute to 'change' practices advocated in mathematics research, we anticipate there will be particular interest in the findings by mathematics teachers, particularly in the potential affordance of capitalising on audience effects in the digital design for learning of peers.

THEORETICAL PERSPECTIVES

This study is informed by theories that conceptualise learning as a socially mediated process (Vygotsky, 1978) wherein SC-DLOs can be conceived as supporting active knowledge construction through both digitally mediated creation and interaction (Smith & Kennett, 2017). From a constructivist perspective

(Ackermann, 2002), learning is potentially enhanced through the active engagement afforded by SC-DLO processes of creation and interaction that includes: (a) connecting new knowledge to existing knowledge as students actively construct digital representations for an audience; (b) cognitive processing benefits by combining visual, verbal and other modes to enhance understanding (c) social interaction 'inside' and 'outside' SC-DLOs as shared objects for discussion and collaboration (d) increased engagement as students creatively use digital media to represent and teach academic content. We offer the following definition of SC-DLOs in line with constructivist principles as:

a process wherein students learn as they design for the learning of others (e.g., designing for teaching and knowledge building), and as a reusable digital entity (or object) designed with the affordances of different media modalities (e.g., textual, audio, visual, spatial, kinaesthetic). (Rosedale, Jesson & McNaughton, 2019)

The 'product' aspect of SC-DLOs extends constructi*vist* views to incorporate construc*tion*ist perspectives. Papert and Harel (1991) maintain the building of knowledge structures happens "felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the Universe" (p. 2). How learners creatively project ideas and inner feelings into public artefacts, engage in conversation about them, and how these conversations boost self-directed learning is considered integral to the construction of new knowledge (Ackerman, 2002). More specifically, student multimodal representation of concepts, understanding and critical reasoning with digital tools is aligned with more general findings of enhanced motivation (Zheng, Warschauer, Lin & Chang, 2016) and with engagement, personalisation and autonomy in our research in digital environments (Jesson, McNaughton, Wilson, Zhu & Cockle, 2018). Where students are offered creative agency to construct representations of academic knowledge, opportunities exist to draw on personal funds of knowledge (Moll, Amanti, Neff & Gonzalez, 1992): backgrounds and experiences that tie institutional knowledge to identity, culture and personal histories. Research also shows improved learning outcomes in the teach-to-learn literature, when students have opportunity to adopt the identity of teacher/instructor or 'knowledgeable other' (Gartner, Kohler & Riessman (1971).

Student learning-design work is theoretically associated with desirable 21st century skills. In designing instruction for other learners using multimodalty affords transformative redesign work (New London Group, 1996) involving creativity, perspective taking, critical reflection, collaborative reasoning, and self-regulation (Lai & Viering, 2012). However, Cope and Kalantzis (2017) argue it takes reflexive e-learning ecologies to promote these kinds of skills and dispositions. They maintain, in reflexive digital ecologies, learners are positioned with "considerable scope and responsibility for epistemic action" (p. 11). In other words, within a framework of planned learning, teachers involve students in knowledge representation activities that creatively extend the knowledge of the classroom community of learners. In technology-supported teaching and learning Hughes (2005) proposes classification of three categories in which technologies can function in classrooms: (i) *replacement* (ii) *amplification*, and (iii) *transformation*. In *replacement*, the technology serves a different means of achieving the same goal (e.g. content is presented on a Microsoft PowerPoint® slide instead of on paper), and *amplification* leverages efficiencies or greater utility such as sharing electronic versions of content for simultaneous access and annotation. But *transformation* is said to exercise technological affordances for creative reorganisation of content, cognitive processing and problem solving (Pea, 1985). Similarly, in the SAMR model (Puentedura, 2006) *Substitution* and *Augmentation* are more aligned with digital enhancement, whereas *Modification* (significant redesign) and *Redefinition* (previously inconceivable without digital technology) constitute transformative application. Both frameworks emphasise the potential danger of routine replacement or amplification, rather than transformative learning opportunities. We maintain that if students are positioned to create SC-DLOs as a design-for-learning practice, there is the potential for leveraging transformative affordances in the hands of learners as learning designers.

However, concerns have been expressed about the 'correctness' of student-created digital objects for teaching others and the potential impact of imprecise conceptual and procedural representation on peers (Croft, Duah & Loch, 2013). Cautions include the need to ensure proficiency with media tools (e.g., editing, captioning, replay) and the time cost for complex design projects. On the other hand, community review and a degree of technological risk taking are increasingly recognised as everyday features of 1:1 learning to mediate these pitfalls (Kearney, 2010; Shaffer, 2010; Yang & Wu, 2012). Theories of knowledge building in digital contexts advocate collaborative, creative agency through open-ended tasks, accompanied by collective improvement to support accountability, both to other learners and to knowledge representation. In this way, classrooms might act as self-auditing cultures, subject to peer review, for example in content curated on a learners' or class blog site. Scardamalia and Bereiter (1995) maintain knowledge-building communities are those in which members are engaged in producing knowledge objects: "though much more modest than Newton's theory" but which "lend themselves to being discussed, tested and so forth…and in which the students see their main job as producing and improving such objects" (p. 270).

Theoretically, at least three dimensions of learning within knowledge building communities can be enacted through SC-DLOs, while also aligning with the identified mathematics 'change' practices. The first dimension is diversity of representation. SC-DLOs afford a *process* effect as multiple modes (e.g. voice, image, gesture) are combined in diverse representations of conceptual understandings using mathematical discourse. Synaesthesia is conceived as switching between modes in complementary ways to achieve a multifaceted understanding "through the juxtaposition and transposition of parallel or complementary modes of meaning" (Kalantzis, Cope, Chan & Dalley-Trim, 2016).

The second dimension of mathematics knowledge building is discursivity. Through sharing and collaborating with SC-DLOs, the opportunity to 'predict' and respond to others' thinking arises from what Jewitt and Parashar (2011) term "shareable" affordances; joint access through online platforms (blogs, discussion boards, Google community) and characteristics that promote critical interaction and visibility of thinking.

Arguably, the other two dimensions provide both a dispositional and practice foundation for a third dimension, namely the ongoing collective *improvement* of a community's knowledge artefacts. Here Bereiter (2002) makes the distinction between conversation that "merely shares knowledge" (p. 183) and conversation that creates further knowledge. For example, creating SC-DLOs has been found to heighten student awareness of collective improvement aims by enhancing performativity; the desire to 'get things right' for the community of learners (Croft, Duah & Loch, 2013).

Summary of Theoretical Integration

The educational literature of contemporary, mathematics indicate calls for change practices that include active student participation in mathematical discourse (Boaler & Sengupta-Irving, 2016), problem solving investigation (Bailey, 2017) and collective knowledge building (Hunter, 2005, 2008). The research into SC-DLOs indicates a number of digital mechanisms which are aligned with these goals, namely multimodal digital representation of students' knowledge, shareability of objects on digital platforms and collective improvement through critical discussion. Evidence from both literatures suggests SC-DLOs might contribute to the change goals prevalent within mathematics educational research to consider 'new' 21st century ways of doing mathematics. A grounded investigation of these characteristics, using a corpus of mathematics SC-DLO, was guided via four related sub-questions:

1. What opportunities (form and frequency) do students have to share mathematics SC-DLOs to their learning blogs?
2. How do students use multimodality in their SC-DLOs to actively participate in mathematics 'change' practices: discourse use, conceptual representation and problem-solving investigation?
3. How do students' SC-DLOs exhibit creative and diverse ways of sharing mathematics knowledge in their community?

4. How do interactions support knowledge building practices with SC-DLOS that include collaborative improvement?

METHOD

Data Collection

A sample of 155 SC-DLOs were collected from students' classroom blog sites in nine schools from within three 1:1 clusters of schools in New Zealand. The clusters predominantly serve lower to middle income families, with large populations of Pasifika and Māori students, and where improved educational outcomes are operationalised as cluster-wide goals. Across a six-month time period, purposive sampling of SC-DLOs created by Year 7-8 students (aged 11-12 years) determined the most frequent blogger, male and female, in each classroom per term. The rationale for selecting from a Year 7-8 sample was based on the assumption that senior primary students would have considerable experience in DLEs across year levels in the 1:1 programme and were therefore more likely to demonstrate accumulated skill in creating digital objects, and associated knowledge building practices (e.g. sharing and discussing the SC-DLOs posted to their learning blogs). Selecting the most frequent male and female blogger in each classroom was expected to capture both range and engagement in digital creation of motivated bloggers. More frequent bloggers were also hypothesised to have more chance of exhibiting the full range of SC- DLO opportunities offered by teachers.

The participating schools are partnering in a schooling improvement initiative that adopts a common programme of creating and sharing learning digitally. For example, each student has a personalised blog site which is used to upload, post and comment on digital artefacts representing classroom and home learning across subject areas. Identification and collection of SC-DLO data into an Excel database followed a systematic process, as follows:

First, individual learner blog sites of all Year 7-8 classrooms were reviewed and all content posted by the selected bloggers (n=1977) between February and June was classified as either SC-DLA or SC-DLO. Each post was first read to identify uploaded SC-DLOs. The associated hyperlink and general features of the SC-DLOs (e.g., classroom code, student de-identifier, medium, month created) were included in the corpus database where there was demonstrated evidence of:(1) a reusable digital object as video, animation, slide presentation, podcast, screencast, film, e-book or interactive graphic; (2) student design or co-design (e.g., with a peer or teacher); (3) some explicitness of learning for others in design purpose, genre or activity description (i.e., not for teacher assessment alone); and, (4) using digital multimedia or multimodality within the SC-DLO composition (e.g., not merely photographs). Therefore, the following examples of SC-DLAs were excluded: games, personal recount or digital story (e.g., narrative) where there was no obvious attempt to explain concepts or ideas to others. Where a students' pedagogic intention was considered borderline (e.g., blog post signifies statistics warning against polluting local streams, but animated narrative includes only indirect reference in the storyline) the digital object was included as a means of erring on the side of inclusion (rather than exclusion). These cases were found to be infrequent as most embedded media objects were found to be skill demonstration or conceptual explanation and therefore well aligned with SC-DLO instructional purposes. Inclusion was based on Churchill's (2007) notion of DLOs as: a) contained, reusable digital objects with multimodal content units (e.g., slide presentation, screencast, podcast, animation, video, film, interactive graphic); b) curriculum-based instructional features (e.g., "My name is Josh and I'm going to show you how to do algorithm in standard written form").

SC-DLOs representing mathematics content were filtered from the complete corpus from18 schools (including other subject areas) into a separate Excel database. Only data from the nine schools with available mathematics SC-DLOs are featured in the analysis: the remaining schools are not included in any of the frequency calculations. Titles and statements of learning intentions or objectives associated with the SC-DLOs showed a range of mathematical curriculum content including: number knowledge, algebra, measurement, geometry and statistics.

Data Analysis

Qualitative Analyses

The resulting sample was analysed using a hybrid approach involving deductive categorisation of general characteristics (e.g., genre, media type, modality) and grounded induction (Strauss & Corbin, 2007). The unit of analysis was the SC-DLO, so that each row in the database was dedicated to an SC-DLO uploaded by the students as a blog post (by school, classroom, year level, date) with columns representing the categories. Open and axial coding were employed towards the generation of an overarching conceptual framework of design-for-learning features representative of the SC-DLO corpus.

As each subsequent SC-DLO was identified, a new row was added to the database and a process of microanalysis was undertaken using open coding to account for the features. The SC-DLO was *read* through (e.g., line by line or frame by frame) and categories were assigned to: general features (e.g., author, school and cluster identifiers, gender, year level, term); subject area and any stated learning intention (e.g., "Be able to perform complex operations using rounding and compensating"); SC-DLO medium (e.g., slide presentation, video, podcast); mode types used in the composition (e.g., writing, image, audio);and genre (e.g., demonstration, explanation).The Grounded Theory (GT) principles of coding, questioning, constant comparison, and selective category groupings were adopted to achieve a conceptual 'intimacy' with the data and emerging patterns (Charmaz, 2006) including the design-for-learning features. Categories included modal effects (e.g. stress such as colour; movement; rehearsal) to amplify meanings; modal combinations (e.g. decorative only; mashup; remix); level of creative response afforded by the task (e.g. open; closed); interaction (e.g. co-authorship; online feedback); making personal connection (e.g. family; culture; identity). Patterns and relationships between codes - axial and back coding - were captured in analytic memos (Urquhart, Lehmann & Myers, 2010). Theoretical perspectives holding explanatory power for the identified associations were then drawn upon and memoed, for example, multimodal constraints within student creations were associated with teacher templates constituting closed tasks. In our related research in the 1:1 clusters, open-endedness has been found to afford complex engagement including multimodal composition (Jesson, McNaughton, Rosedale, Zhu & Cockle, 2018).

Selected categories representing core concepts related to the SC-DLO features formed the final framework: representation (form and level); language/concept amplification; personalisation; and collaborative interactions. This framework was used to consider evidence of the desirable change practices previously identified in mathematics literature: student participation in mathematical discourse, problem solving investigation and collective knowledge building. Rich, and representative descriptions were tagged for illustrative purposes. All student names have been substituted to protect their identities and all screen shots of blog sites have been cleared of any attribution references.

Quantitative Analyses

Descriptive statistics were used to determine trends by variables such as school, classroom, subject, media type and genre. To quantify opportunities students had for creating SC-DLOs frequency counts were undertaken comparing SC-DLAs to SC-DLOs (as operationalised earlier).

FINDINGS

What Opportunities (Form and Frequency) Do Students Have to Share Mathematics SC-DLOs to Their Learning Blogs?

Frequency of students' mathematics SC-DLOs shared to blogs demonstrated extreme variability across schools. Blog posting of SC-DLOs featuring mathematics content occurred more often on average in Term 1 (4.2 posts per student) than Term 2 (3.2 posts per student). In comparison to other subjects, mathematics was more often represented as SC-DLOs than other curriculum areas such as reading, science, social studies (or integrated studies), health/PE and religious education. However, this was due to higher rates at one particular school. Excluding this school, frequencies of SC-DLO creation showed student mathematics posting to blogs at 2.8 SC-DLOs per student in Term 1 and 1.6 SC-DLOs per student in Term 2. Furthermore, nine schools (50%) were excluded from the corpus as there was no evidence of mathematical SC-DLOs. These patterns suggest, except at one school where online sharing of mathematics SC-DLOs occurred more regularly, SC-DLOs were not a salient feature of the wider blogging programme in mathematics. In at least half of the schools, students were not posting mathematics SC-DLOs at all. Students' mathematics knowledge sharing was in many cases underrepresented across a sizeable cluster of 1:1 schools.

On the other hand, in terms of form, there was little variability in the tools used to create SC-DLOs: presentation using Google Slides (88%) and screencasts (12%). Given the overwhelming default to slide presentation, there appears to be considerable scope for encouraging other SC-DLO mediums, for example, podcasting provides specific learning affordances that target oracy and close listening. In terms of genre classification, demonstration was the most prevalent followed by description, explanation and limited representation of argumentation.

How Do Students Use Multimodality in Their SC-DLOs to Actively Participate in Mathematics 'Change' Practices: Discourse Use, Conceptual Representation and Problem-Solving Investigation?

Findings related to variation in student use of multimodality to actively create meaning (e.g. discourse, concepts, problem solving) are described as two interrelated aspects of form and level. Features of each SC-DLO type (form) will be described in relation to opportunities for design for learning in active, transformative ways (level).

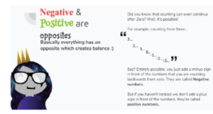
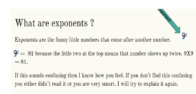
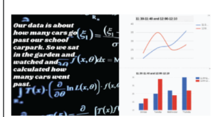
Presentation Form

Slide presentation SC-DLOs created from a teacher template (67%) tended to constrain students to the use of print (writing) with aesthetic or decorative components These typically constituted a *transmission* level of meaning making using worked examples. SC-DLOs categorised as transmission included skill and drill routines through a type of digital worksheet with visual stimulus (e.g., pizza cut into slices). This use of slide presentations did include opportunity for students to transpose numerical equations into word problems for peers to solve. But in both cases, transmission and transposition, multimodal design was limited to pictures which served as visual or symbolic links to everyday contexts, rather than students' amplification and transformation of mathematical meanings. Contribution to the SC-DLO design could be categorised in these cases as a low-level type of mashup. SC-DLOs framed by teacher templates that focussed on a problem solving investigation offered more opportunity to communicate strategic and critical thinking, although again, the tight scaffolding tended to constrain student multimodal design. For example, students were directed to use the internet for 'real world' problem solving in contexts that included house renovation, travel to a budget, scheduling flights factoring in time zones, and statistical surveys.

In contrast to these teacher-templated tasks, students also responded to 'open-ended' directives (33%) by authoring from the ground up. Open-endedness of the task instruction allowed for considerably more variability in design interpretation, modal combinations and organisation. With open-ended opportunities for multimodal assemblage students were found to extend, or synaesthetically support meaning making with features such as complementary annotation, mathematical figures (e.g., graphs, diagrams, tables) and conceptual explanations. An interesting feature of students' designs in response to open tasks was the inclusion of social discourse combined with mathematical discourse such as demonstrating empathy and offering advice from personal experience of mathematics practice. The variability in synaesthesia to support audience understanding are collated in Table 1.

Use of social discourse was categorised as a personalising affordance that worked to create bridges from students' informal to formal knowledge. An example of this personalisation (Figure 1) is shown

Table 1. SC-DLOs Demonstrating Variability in Synaesthesia to Support Audience Understanding

Topic	Genre	Synaesthesia	Key entities	Discourse features	Example
number knowledge	explanation	Verbal concepts amplified by colour adjacent to visual of descending number line	number line	*scientific:* "These are the equations…" *social:* "But if you haven't noticed we don't add a plus sign in front of the numbers…"	
geometry	explanation	Annotation (arrows and circles) amplify concept: "Each bar has been *translated* upwards"	photographs	*scientific:* "In a translation, every point of the object must be moved in the same direction and for the same distance."	
algebra	explanation	Annotation (arrow) connects verbal (exponent) to visual: "the little two at the top"	diagram	*scientific:* "We know that five will show up in the equation twice…" *social:* "If this sounds confusing I know how you feel…I will try to explain it again."	
statistics	argument	Verbal description juxtaposed with visual illustration: "This is the timing of our recording."	graph	*scientific:* graphed data as frequency and trend *social:* "Hey, there goes another car." "Yeah ok that makes it 20."	

by Matt and Malo's design of mathematical figures representing time series data. A tally chart of traffic frequencies on consecutive mornings has been labelled 'time series data' (formal) preceded by their headshots superimposed on suited models (informal). They use conversation bubbles to demonstrate the sampling method using everyday 'street talk' ("Yeah ok, that makes it 20").

The rendering of context (with intertextual link to a *Men-in-Black* movie style) and formal statistical procedure (time series), suggests appeals to the peer group, and a scaffold for the audience. In other words, they provide an everyday rendering of the mathematical method using a humorous, colloquial design that is mathematically instructional.

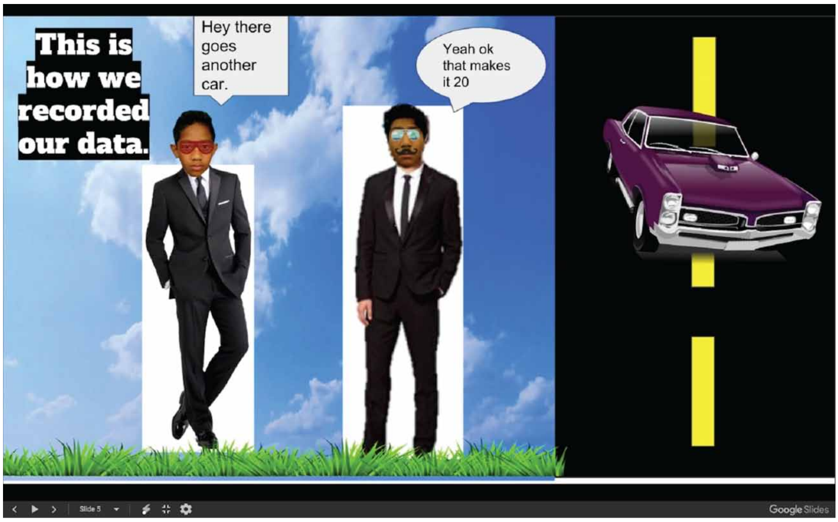
In summary, although slide presentations offered the means of embedding a variety of multimodal forms to represent mathematical meaning, student design-for-learning choices were somewhat constrained by teacher template design. But opportunities to combine design with authentic investigation (using 'real world' data' and the agency of more open tasks, appeared to yield hybrid compilations which illustrated personalised meaning within a context. Rather than detract from formal mathematical meanings, personalising features appeared to scaffold mathematical understandings in an engaging, youth-centred way.

Screencast Form

By comparison with slide presentations, screencasts only represented 12% of mathematics SC-DLOs and included the following subject areas: operations on decimals, fractions and percentages (conversion, addition, and multiplication), results of statistical inquiry and using place value to solve problems.

During screencast demonstrations students typically foregrounded a mathematics application (such as *MathsBuddy©*[3]) in a web browser, with a webcam overlay in the right corner for audio narration. These SC-DLOs tended to feature modelling, designed to enhance procedural visibility. Students foregrounded the onscreen presentation of a mathematical equation (or word problem) and simultaneously recorded verbal commentary of the mathematical process they had undertaken. Screencast video provided additional support for learning by including vocal intonation such as emphasis (e.g., "we divide 30 by the *denominator*, which is 3"), and the cueing of audience attention

Figure 1. SC-DLO demonstrating a bridge from informal to formal



with the mouse pointer or draw tools. These features demonstrated design-for-learning potential through multimodal meanings: verbal commentary supporting understanding of the procedural notation and vocal emphasis used to name mathematical terms or concepts.

Like the slide presentations, audience awareness and empathetic response were strong features of screencasts as students anticipated perceived difficulties or offered tips and cautionary advice. For example, "So 9.7 minus 2.2. *Just have a little think*. What would that be?" (pauses to offer wait time), and "These are fractions of a whole number, another Year 9 task…Year 9, it's a bit harder than we usually do, *but I think we can manage*".

Conversely, there were cases where the needs of an audience were entirely overlooked, and students appeared to focus on the speed of their calculations rather than anticipating an audience's need for understanding. Where students explained why procedural steps were warranted, conceptual understandings were made visible. For example, adding seven hundredths to eight hundredths, Max pointed out he only added the numerator because the denominators are the same (implying equivalence), and then he concluded with "we're going to simplify that by dividing by 5". Elaboration provided by students in explain and describe genres, promoted visibly of the student "think aloud" which highlighted both what students did, and did not understand, affording potential for teacher (and community) intervention.

Amplification of Language and Concepts

The multimodal features used to focus audience attention on mathematics language (e.g. discourse; terminology) were found to be more evident in slide presentations than screencasts. Although design aspects such as colour and size were used for aesthetic purposes, such features were specifically analysed for use in signalling mathematical meanings. For example, colour, annotation, and movement were used as devices for drawing attention to mathematical language, and procedural steps: "What you would do first is you would see the word **M**ultiplication in the word **B.E.D.M.A.S**, the **M** is before the **A** and the **S**…5x9 which equals 45".

In screencast SC-DLOs, students more often used tools-in-motion to circle or underscore numerical notation as they performed the calculations in real-time. Although useful as pointing devices, these tools were less likely to amplify attention to conceptual language. For example, screencast demonstrations of mathematical strategies (such as simplification and compensation) showed students talking about dividing by 2 till it could go no further, or adding 3 to make 20 without taking the opportunity to formalise using mathematical discourse. These findings signal opportunities to explicitly teach students' design-for-learning strategies such as: editing screen casts to add pop-up captions; building metacognitive awareness of enhanced learning for the audience by simultaneously presenting and saying the word form when explaining mathematical concepts. Although the screencast tools for free-hand captioning or onscreen text animation were available within the apps students used, they were less likely to engage in post-hoc editing to rehearse terminology as authentic vocabulary practice. They were also unlikely to use the app highlighting tools to draw attention to key entities like signs, symbols or key terminology. Therefore, there appeared to be considerable scope for capitalising on app-specific design features as a means of accentuating mathematical discourse. Definitions of mathematical terminology were almost exclusively provided in slide presentations, and were almost absent in screencasts.

In summary, SC-DLOs revealed how features of mathematics discourse could be both amplified and rehearsed creatively and authentically using digital features. Communicating to students the significance of foregrounding language in their digital meaning-making could raise the profile of formal use of mathematics discourse in more precise, academic ways, and particularly in screencasting where it was less evident.

How Do Students' SC-DLOs Exhibit Creative and Diverse Ways of Sharing Mathematics Knowledge in Their Community?

In both forms of SC-DLOs, personalisation was found to be a salient feature of communicating formal mathematics to a learner audience. Students were also found to project their identities and make connection to their backgrounds including experience, identity and culture in the following ways.

Digital Self-Representation

Open-ended authorship of SC-DLOs consistently featured the embedding of students' actual recorded voice, video capture and photographs as a form of digital *embodiment*. Self-representation 'within' everyday mathematics learning artefacts is a new phenomenon of 21st century digital classrooms and reflects socio-cultural influences of contemporary social media. For example, evidence of YouTube culture was strongly evident in the way students assertively presented themselves as authorities in the popular 'how-to' online genre. Interactive collaborations between co-presenters (particularly in video) were highly personalised with humour, acting-out and taking on roles such as scientists, demonstrating on-the-fly explanations, and modelling. Noticeable features included an 'unselfconscious ethos' about admitting mistakes, making appeals for assistance and recommendations based on prior experience. These real-time records of personalised, and peer-to-peer ideas exchange, present real opportunities for making thinking visible within communities for discussion, feedback and reflection. Evidence of responsiveness to diverse representation is a theme that will be taken up in a later section.

Creative Thinking as Analogical Reasoning

Perhaps because SC-DLOs offer opportunities for freedom of expression, unprompted analogy and strategic thinking was consistently made visible for the audience. For example, an onscreen discussion shows Jessie turn back to the camera, as an after-thought, to suggest the viewer think about the decimal notation like a "digital clock": where whole minutes or hours are positioned to the left of that which she described as "less than a whole" (on the right). Others suggested thinking of the BODMAS acronym like "Lol=Laugh Out Loud", "where each letter stands for a certain word", and when ordering decimals: "Think of them [0.68 and 0.56] as money, one costs 68 cents and the other 56 cents…and because six tenths is bigger than five tenths". These findings suggest SC-DLOs can offer affordances for capturing student-oriented mathematical strategies that may facilitate adoption by the SC-DLO learner-audience.

Connections to Home

Links directly with doing mathematics at home, or in making connections to cultural background, were scarce, but took the form of inquiry support. For example, an SC-DLO that referenced parent/caregiver assistance with an investigation into plastic bag distribution at store checkouts. The frequency of plastic bag purchase was time sampled and graphed by the student in a slide presentation to support researched statistics on ocean pollution: "This is the information my mother provided during 5 and a half hours at work…'.

Creative Artistic

Personalisation was also observed as creative license in students' choice of setting (e.g., playground; library; superimposed backdrops of photographs or mathematical symbols), soundtracks, and use of animation such as GIFS. Music backing tracks served a functional purpose (beyond in- and out-takes) to eradicate the distraction of ambient classroom noise (which a couple of students openly apologised for not being able to mute).

How Do Interactions Support Knowledge Building Practices With SC-DLOs That Include Collaborative Improvement?

Patterns of interaction both 'inside' and 'outside' SC-DLOs were found to offer new mechanisms for collaborative knowledge building practices. 'Inside' affordances occurred within the content of the SC-DLOs as:

- Co-authoring (e.g., attributions to peers as collaborators);
- Live embodiment of the students (e.g., video capture of turn-taking to explain steps for solving an equation; photographed collaboration);
- Coded buttons and intertextual hyperlinks (e.g., provision for viewer selection of answers that were checked to be correct or incorrect; viewer use of hyperlinks to other digital texts such as a YouTube video or peer's SC-DLO).

'Outside' SC-DLO interactions occurred as blog comments and provided a visible means of asynchronous feedback: "I think you explained this really well Rashaan. I *also learnt something new*, Standard Written Form".

The findings related to knowledge building practices are presented hereafter as first 'inside' and then 'outside' interactions.

'Inside' SC-DLO Interaction

Interactions that involved verbalised mathematical reasoning tended to occur inside the SC-DLOs as captured discussions, either as voice-over, or as video insert. This is an important finding as most SC-DLOs were individually (87%) rather than collaboratively authored (13%). For example, screencasts typically featured a lone student computing algorithms or equations. Although the screencast technology affords 'getting inside students' heads' during video think aloud, limitations included students' default to procedural rehearsal, rather than the kinds of deliberation that makes reasoned decision making visible to an audience. However, during screencasting with a partner, collaborative reasoning occurred more spontaneously. For example, where Ana and Erena were explaining the ascending order of decimals, Erena corrected Ana's interpretation of ascending and explained 'that's from smallest to biggest". Opportunities for dialogic argumentation did not appear to occur naturally and suggests the need for teacher design of activities that promote collaborative reasoning and problem-solving debate.

The visibility of SC-DLOs on the leaners' blog platforms offered opportunities for providing collective assistance as a community of learners. For example, some students were surprisingly candid about having to do extra practice because they "didn't get it" or suggested the viewer seek out other demonstrations because theirs was limited compared to their peers. But reciprocity, by way of feedback in response to such requests was somewhat overlooked by the online peer community. For example, Jack's reporting of the graphed frequencies of his team's "basketball shots investigation" used a pie and bar chart to amplify the differences in the shot rates. Jack reports "11 as the average of 7 students, if everyone got 23" (the highest score). Community accountability to these sorts of errors, such as Jack's misrepresentation of average, would require nurturing a classroom culture of regular, multi-faceted review routines. Other examples of imprecise working and confessions of difficulty suggested ample opportunity for the peer community to lend support, promoting the kinds of real world, academic peer review and accountability to the improvement of collective work.

Similarly, interaction in the form of embedding intertextual links to peer's SC-DLOs or other text models (e.g. Khan Academy videos) was scarce and primarily found in teacher templates. There were only a few instances where students included links to peers' SC-DLOs, or to mathematics texts they had sourced and evaluated themselves. There would appear to be opportunity to further promote students' own text choices, both of peers and internet sources, to extend intertextual referencing within SC-DLOs.

'Outside' SC-DLO Interaction

The posting of SC-DLOs to a blog platform provided the means for interaction with SC-DLOs as texts for commenting on. But blogged feedback comments were infrequent across the sample (24%). Moreover, it was rare that comments developed into discussion strings, or the kinds of criticality that constitute reflective improvements about mathematical knowledge. Family were the occasional exception, with parents responding in both evaluative and encouraging ways ("… only a few mistakes which shows that you're getting the idea! Proud of you!"). But by and large, students tended to offer general praise (e.g., "Keep up the great work!"), which was kind, and encouraging, but arguably offered little in terms of transforming knowledge collectively. If an established affordance of shared digital artefacts is 'rewindability' and 'visibility', it would be important to build normative practices that encourage peer-to-peer accountability, and improvement purposes. The "outside" interactions within this sample revealed negligible examples of reasoned evaluation of this kind.

DISCUSSION

Answering the overarching question, "How do SC-DLOs demonstrate 'new' 21st century ways of doing mathematics?" has yielded considerable evidence supporting the change practices called for in contemporary mathematics literature. The evidence however, is variable across contexts, and suggests that the creation and sharing of SC-DLOs for knowledge building is quintessentially a matter of purposeful pedagogical design. Although SC-DLOs shared on learners' blogs showed transformative kinds of design-for-learning practices (e.g. collaborative screen-cast demonstrations) there was also considerable evidence of replacement practices (Hughes, 2005) or closed tasks, where student design was constrained by the predesigned teacher templates. The SC-DLO forms (e.g. screencasts) and online platforms such as shared learning blogs indicate that the digital ingredients exist for promoting ambitious sorts of design-for-learning practices in mathematics in 1:1 contexts; digital creation practices that hold affordances for participation in mathematics discourse, investigative problem solving and community knowledge building. Therefore, the balance of this discussion will be framed as four key implications, aligned with the findings from the four research questions, to provoke transformative learning-design conversations.

Implication 1 - Widening the Scope for Forms and Frequency With Which Students Share Mathematics SC-DLOs

Inquiry into the forms and frequency of SC-DLOs in the corpus (research question 1) indicates there is an argument to be made for more scope, and opportunity to create SC-DLOs in mathematics. If the most frequent bloggers in these 1:1 initiatives were sharing around one to four SC-DLOs a term (i.e. in 9-11 weeks), it is likely there are opportunities for substituting some skill-and-drill with digital apps and worksheet practice work (closed task) for more complex thinking of SC-DLO work (open task); particularly the kind that theorises SC-DLO practices as shared knowledge building, rather than artefacts that merely capture a record of the learning (covered further in implication 4 below).

Task open-endedness appeared to give students opportunity to employ a wider range of digital modalities incorporating personal expression and skill, alongside formalised representations of mathematics. Open-ended did not imply unfettered agency, where students were left to their own devices as a form of unrestrained discovery. On the contrary, comparisons of SC-DLOs from the same classroom suggested increased diversity of SC-DLOs with wider task parameters, where engaging with diverse multimodal representations of mathematics offers opportunities for critical discussion. This is in line with a number of constructivist learning principles advocating planned student reflection towards resolving discordant or representational difference. Going beyond practice exercises and problem solving for the right answer, SC-DLOs afforded recorded explanations for contrasting conceptual understandings. Teacher templates, typically as presentation slides, positioned students in 're-transmission' roles; making copies and adding content in accordance with teacher creative designs. The default to slide presentations as an SC-DLO form suggests there are transactional benefits for teachers and students (e.g. dissemination of practice activities; embedding hyperlinked resources). But an unintended consequence may be students' default to slide presentations as routine, and thereby constraining what Hughes (2005) regards as *transformative* technological use.

In terms of implications for teacher practice, there appears to be room for some alternatives to templates, such as check lists or criteria frameworks to guide more open design-for-learning support by students. Creation of SC-DLOs in response to more open-ended tasks would require design support as representing mathematics knowledge with multimodality involves complex reorganising decisions and outcomes monitoring. But we see these challenges as being well aligned with 21st century digital contexts and skill development in line with multimodal meaning making (Cope & Kalantzis, 2017; New London Group, 1996). The findings also suggest students variable use, and therefore awareness, of design for learning supports. This is taken up in the next implication.

Implication 2 - Leveraging Multimodal Design-for-Learning Affordances Through Students' Participation in Mathematics Change Practices

Student-creation practices suggested SC-DLOs build increased expectation for communicating mathematics with an audience (e.g. adopting a teacher persona; offering strategic advice; demonstrating empathy) as one feature of promoting multimodal design for learning. Apart from the established potential of digital authorship to enhance motivation for young people (Zheng et al, 2016) raising the *profile of audience* suggests a somewhat new mechanism of elevating engagement, and purpose in mathematics. This does not negate the importance of traditional approached to building mathematical fluency, but SC-DLOs offer communication with an audience as *additional* and *different* means of promoting capability. Evidence of design for learning features (such as audio explanation, video modelling, annotation and complementing explanations with mathematical figures) necessitate the use of complex mathematical discourse, and modal combinations. Arguably it is such features which have the potential to enhance students' discourse participation in ways educational change commentators advocate (Boaler, 2008; Hunter, 2005). However, students did not appear to be drawing on a framework of negotiated design principles that furthered learning design aims as a community. Employing design features for learning tended to be rather haphazard, so that striking more of a balance between templates (with high levels of constraint on creativity), and sparse guidance (as indicated in screencast design), warrants student-friendly conceptual tools to support knowledge design in the hands of students. This would look less like students filling in the gaps, and more like guiding principles which are co-constructed, and which scaffold students' design agency.

If audience can be considered one such design-for-learning principle, then cueing big ideas or concepts was another. Students' use of slide presentations facilitated embedding of objects, including screencast video, aimed at remixing content into what Domingo, Jewitt and Kress (2014) call *modules* of meanings i.e. hyperlinks and embedded objects that cohere and amplify big ideas. In line with multimodal design principles, Mayer (2014) has found that cueing or signalling, to amplify meaning, is an important feature to isolate and attend to key messaging, which strengthens recall. On the whole, the use of cueing devices was evident, but particularly limited in screencasts. Like Soto (2015), these findings suggest default to using the pen tool in screencasts which could be extended to go beyond procedural demonstration through explaining links to concepts. In a constructivist sense, modelling that incorporates explanation moves beyond recall to tapping conceptual mental structures. In a design-for-learning sense, students can be guided to reflect on which key ideas need emphasis, anticipate audience misunderstanding and include points of emphasis and elaboration in response. Opportunities for broadening the scope of SC-DLO form (e.g., podcast, animation) and screencast tool use (e.g., backlight, isolate; circle) can assist with building awareness of these cueing principles, and appreciation of the importance of highlighting conceptual language for learning. The intertextual resources, provided by teachers (such as hyperlinks to YouTube videos in teacher templates) had strong examples of amplification in 'how to' explanation genres, as typified by a well-used algebra video (Figure 2). However, the editing used to overlay key conceptual terms (e.g., Figure 2; co-efficient) did not appear to have transferred to the design features of student screencasts and suggest avenues for building design-for-learning awareness through such exemplars.

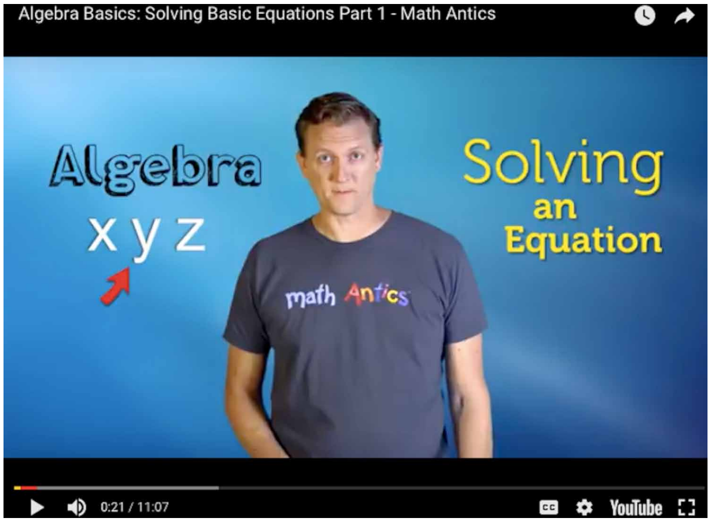
Implication 3 – Personalising Affordances of SC-DLO Creativity and Diversity in Sharing Mathematics Knowledge

As the above implications suggest, digital creativity for knowledge building with SC-DLOs need not be a distraction from legitimate mathematics, nor necessitate unduly long-term design projects (e.g. animation films). Capturing videoed discussion, and student editing for augmentation with language captions and amplification of key conceptual ideas can constitute focussed discourse work. The SC-DLOs that exhibited some of the strongest potential for learning were those including personalised representations of knowledge which provided a bridge to formal mathematics. These features are in line with opportunities to creatively redesign meanings (New London Group, 1996) and in connecting prior (e.g. everyday) knowledge with formal, new knowledge (Borg et al, 2016). This was particularly the case where students' 'embodied' SC-DLOs (e.g. self-recording). Mayer (2014) has consistently found improved learning outcomes when learners engage with a human recorded voice and Moll et al (1992) underscore the importance of students making connections to personal histories.

Implication 4 - Interactions that Support Collaborative Knowledge Building and Improvement Through 'Inside' and 'Outside' Interactions

Interactions, both with mathematics texts (e.g. as links inside SC-DLOs), and peers (e.g. discussion inside and outside SC-DLOs), were limited, and therefore constrain interpretations of collaboration and co-authorship. The absence of interpersonal interactions with other students' SC-DLOs, as texts worthy of referencing or via forms of collaborative digital embodiment (e.g., in videos) was somewhat discordant with the vision of collective knowledge building (Scardamalia & Bereter, 1995). Where students used screencasting together, they were more likely to interact by inadvertently capturing disagreement on camera, or by alternating roles: the partner providing further detail, or a complementary analogy. These are important findings that might suggest the value of substituting some of the lone student screencasting, for collective recordings, to promote the kinds of collaborative reasoning advocated in the growing dialogic knowledge base (Hunter, 2005; Mercer & Sams, 2006).

Figure 2. Screen shot of Algebra Basics video demonstrating post-editing with text overlay. Reprinted from You Tube, n.d. Retrieved 17 January 2019 from https://www.youtube.com/watch?v=l3XzepN03KQ.Copyright 2019 by Math Plus Motion LLC. Reprinted with permission.



Fostering a culture of collective improvement means capitalising on the affordances of shareability in digital environments (Jewitt & Parashar, 2011). Therefore, there appears to be missed opportunities to support the noticing and reflection on difference in others' knowledge representations. The use of blog commenting to achieve these aims was minimally represented in this sample. How much face-to-face classroom interaction is occurring about SC-DLOs cannot be determined here, but if the affordance of rewindable, shareable learning is a valued feature of DLEs, one would expect these interactions be more purposefully designed for archive on the students' learning blogs. A blog arguably provides a platform for conversation beyond the goal of reaching a publishable standard before posting.

The intertextual links 'inside' SC-DLO templates were almost exclusively contributed by teachers to web-based videos such as YouTube and Khan Academy. As these texts demonstrated principled use of mathematics (such as strategy use) there was no apparent cause, or indeed any noticeable directives, for students to engage in acts of critical reasoning *about* the texts. Possible avenues for such engagement could be to offer more than one text for comparison, that students source their own texts and evaluate according to pre-agreed criteria, or remix parts of the texts (e.g., screen shots or screencast recordings that integrate students' own commentary and language cues about these mathematics texts). Despite the perceived complexity of this sort of authoring, it can be fairly easily achieved with current screencasting tools.

There is however, another important reason for more intentional focus on students using blog commenting and joint screencast recordings, especially if task design purposes critical engagement; that is, the need to adopt prosocial, but critical engagement with others online. From a wider imperative to grow discerning, but tolerant citizenry, young people require opportunities across all subject areas to interact responsibly during critical exchanges in online contexts.

LIMITATIONS

The SC-DLO sample in this study represents authorship uploaded by students to their learning blog sites and therefore may not reflect the full range of creation practices in unpublished artefacts stored in offline learning folders. Similarly, classroom practices would only be available for analysis as recorded interactions, such as group or whole-class discussions about SC-DLOs, if posted to blog sites. Therefore, it is acknowledged that knowledge building with SC-DLOs for improvement purposes will likely be understated, given teachers may be promoting SC-DLOs as exemplars to support face-to-face instruction, or as resources to teach design-for-learning principles. It would be important therefore, to explore teacher and student beliefs and experiences of incorporating SC-DLOs into cycles of learning in classrooms. Furthermore, the sampling method used in this study purposively selected the most frequent bloggers in each classroom. This decision to increase quantity may have been at the expense of design quality by less engaged bloggers, not included in the sample. Stratified sampling will be used in any future studies to mediate such limitations.

CONCLUSION

This study sought to investigate how SC-DLOs may indicate 'new' mechanisms for doing mathematics in 1:1 classrooms. The corpus of SC-DLOs showed multimodal digital authorship is being used to communicate mathematics knowledge in ways that promotes students' use of mathematics discourse, problem solving investigation, and to a much lesser extent, interactions for knowledge building within and beyond classroom communities (Bereiter, 2002). Evidence of audience awareness, use of multimodality and personalisation were strong characteristics of mechanisms for communicating mathematical understanding and promoting interest, whereas features such as amplifying language, critical discussion and student design agency were considered to be more limited. The findings contribute to an emerging framework for enhancing student design-for-learning practices. The prevalence of multimodal creation and student co-authorship in classrooms has recently been found in our work to be a pedagogical feature of effective teachers of writing (Jesson, McNaughton, Rosedale, Zhu & Cockle, 2018). Extreme variability of SC-DLOs in this study – frequency and design choices - may also be related to teacher experience and a willingness to open up design work to students as legitimate mathematics practice. Further investigation is needed to determine teacher and student views of creating SC-DLOs in mathematics and the influence on achievement outcomes. However, it appears that raising the profile of communicating mathematics to an audience through SC-DLOs offers promising mechanisms for disrupting business as usual in classrooms.

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Conflicts of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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ENDNOTES

[1] https://login.mathletics.com/

[2] The term one-to-one is applied to programs that provide all students in a school, district, or state with their own laptop, netbook, tablet computer, or other mobile-computing device.

[3] https://www.mathsbuddy.co.nz/

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