

Building cognitive bridges in mathematics: exploring the role of screencasting in scaffolding flexible learning and engagement

Catherine McLoughlin
Australian Catholic University (Canberra)

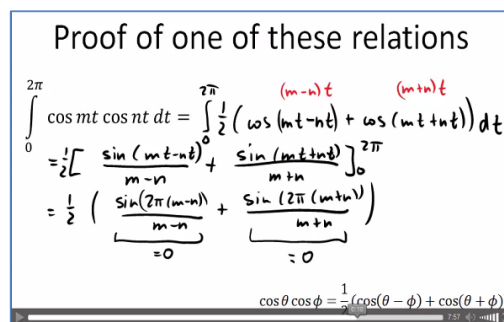
Birgit Loch
Department of Mathematics,
Swinburne University of Technology

Conceptual learning in mathematics can be made more accessible with mathscasts, which are dynamic, digitally recorded playbacks of worked examples and mathematical problem-solving on a computer screen, accompanied by audio narration. Mathscasts aim to enable students to develop deeper understanding of key foundational concepts in order to equip them to undertake degrees in Science, technology, engineering and mathematics (STEM). Previous research has indicated the success of maths screencasts to provide explanations of complex concepts and reinforcement of concepts previously learnt. The project presented here extends current research by demonstrating the value of visual, interactive screencasts for learning of mathematics, and investigates students' perceptions. A survey of student use of screencasts identifies learners' usage patterns, the significance of offering mathematics support via mathscasts in flexible mode, and students' integration of mathscasts into their study strategies. The results show positive implications for the integration of multimodal learning resources in STEM environments.

Keywords: screencasts, mathscasts, STEM, mathematics, multimodal learning, digital learning objects, conceptual understanding, learning sciences

Mathscasts and screencasts: digital learning objects

A key focus in the learning of sciences is to discover principles that determine the optimal amount of instructional scaffolding needed to support effective learning (Stylianides & Stylianides, 2013). Teachers of mathematics and STEM disciplines face the challenge of enabling students to understand and apply complex abstract principles and rules. For over a decade, visual representations have played a role in enhancing learning in science, technology, engineering and mathematics (Fletcher & Tobias, 2005). Research in educational psychology has quite clearly demonstrated that integrating visual and multimedia elements in teaching abstract concepts can enhance learning. This paper addresses the question of how screencasts of solutions to mathematical problems are accessed and used by students and whether they can be considered as cognitive scaffolds that can be integrated into learning environments to support productive learning and study strategies.



Proof of one of these relations

$$\int_0^{2\pi} \cos mt \cos nt \, dt = \int_0^{2\pi} \frac{1}{2} (\cos(mt-nt) + \cos(mt+nt)) \, dt$$

$$= \frac{1}{2} \left[\frac{\sin(mt-nt)}{m-n} + \frac{\sin(mt+nt)}{m+n} \right]_0^{2\pi}$$

$$= \frac{1}{2} \left(\frac{\sin(2\pi(m-n))}{m-n} + \frac{\sin(2\pi(m+n))}{m+n} \right)$$

$\cos \theta \cos \phi = \frac{1}{2} (\cos(\theta - \phi) + \cos(\theta + \phi))$

Figure 1: Screenshot of a mathscast showing a worked out solution to a problem.

Screencasts are video recordings of screen activities, including mouse movements and clicks. An audio commentary is often included with the video to explain the process or problem, thereby providing explicit step-by-step explanation of key topics. While screencasting was originally described by Udell (2005), mathematical screencasts are typically narrated by a lecturer or tutor while handwritten diagrams or figures on the screen are being recorded. Figure 1 shows an example of a mathscast in which a teacher narrates a solution to a problem while simultaneously displaying in writing the process of problem solving in a step-by-step narrative. Mathscasts are produced in a video format (MP4) that may be played back on a wide variety of devices, including those that do not support the Flash format. This decision impacts on the design of the mathscasts. They are compressed heavily to produce file sizes that can be downloaded fast on mobile devices, and usually only part of the screen is recorded, acknowledging that a recording from a full screen of high definition may be difficult to see on a small smartphone screen.

Mathscasts are, in short, typically multimedia demonstrations that explain problem solving with examples of complex equations that aim to accommodate various learning styles (Trail & Hadley, 2010). Mathscasts can be delivered live, in synchronous learning contexts or captured on video and shared, e-mailed, or downloaded from a website (Yee & Hargis, 2010). Mathscasts are also available via iTunes U and YouTube (Loch et al, 2012). Screencasting software allows teachers to record the mathematical activity on a computer screen, draw figures, symbols and graphs, and narrate an explanation while showing the actual working out of a solution. Often tablet PCs are used to enable the instructor to write symbolic and graphical information electronically (Loch, 2012). In view of the international trend to develop learning goals not only in terms of content and procedures, but also in terms of mathematical competencies, mathscasts are intended to develop students' ability and willingness to use mathematical modes of thought (logical and spatial thinking) and presentation (formulas, models, constructs, graphs, and charts) (Lithner et al., 2010).

Multiple Representations support learning: evidence from learning theory

Many learning resources offer multiple representations that can enable comprehension and learning. Textbooks, for example, often use photographic images or diagrams to illustrate and explain parts of the text. In early computer-based learning environments, texts and images were applied in the same way as in textbooks, namely as static images (Lowe & Sweller, 2005). While research on representations in textbooks was relevant for early computer-based learning environments, in contemporary learning settings many dynamic representations are available, including audio, video, animations, and interactive dynamic visuals (Mayer, 2005). With recent developments in eLearning, new opportunities for presenting and engaging learners through dynamic visualisations are evident, and research to study the implications for learning with multi-representational resources is a flourishing area.

Several theories provide principles that explain how to promote learning in multimodal learning environments. Theories emerging for educational psychology relating to cognitive load (Mayer, 2005; Moreno, 2006) are relevant here as they focus on how students process information and they also describe the implications of using visual and interactive media to reduce cognitive load. Typically, as in the case of mathscasts, students are presented with a verbal explanation of the process and a corresponding visual representation of the content. Modality refers to the senses used by the students who receive the information – for example visual, auditory. The research of Fletcher & Tobias (2005) shows that students' understanding can be enhanced by the addition of nonverbal knowledge representations, such as visualisations along with verbal explanations. The research of Lowe & Sweller (2005) provides evidence that the most effective learning environments are those using mixed modality representations. The explanation for this is that mental processing capacity while learning complex concepts can lead to cognitive overload and to reduced retention of new materials. Screencasts provide for the five types of interactivity described by Moreno & Valdez (2005), and are thus considered as powerful supports for learning. Table 1 shows the different types of interactivity enabled in mathscasts and screencasts.

Constructivist learning theory is also relevant in discussing the benefits of multimodal resources as it distinguishes between two views of learning: information acquisition and knowledge construction. In the information acquisition view, learning involves adding information to the learner's memory. Teaching as instructivism involves presenting information and the learner's role is to receive the information. In contrast, in the knowledge construction view, learning involves building a mental representation through active processing of information. From a constructivist perspective, a learner is a sense-maker who works to select, organize, and integrate new information with existing knowledge. According to a knowledge construction approach to learning, the goal of instruction is to guide the learner to actively make sense of the instructional materials, and the instructional design of the mathscasts in this project follows these principles (Bransford et al, 1999).

Table 1: Types of interactivity for learners viewing mathscasts

Type of interactivity	Description	Example
Dialoguing	Learner receives a response to input	Seek help from screencast, click on a hyperlink to get additional information
Controlling	Learner determines pace and/or order of presentation	Use pause/play key or forward/rewind button while watching a mathscast
Searching	Learner finds new content material by entering a query, receiving options, and selecting an option	Seek information on a maths problem or procedures
Navigating	Learner moves to different content areas by selecting from various available information sources	Click on a menu to move from one mathscast to another

When integrating screencasts in synchronous teaching situations, the tools allow the teacher to explore and display different paths to a solution, or modify the explanation in response to feedback from the audience of learners (Galligan et al, 2010). Mathscasts add value as pedagogical learning objects as they provide opportunities for vicarious learning, while offering both visual and auditory demonstrations of solutions to mathematics problems. Mathscasts can be converted to short downloadable video files for use during review and reflection.

An advantage for teachers is that screencasts are relatively quick to prepare and easy to update and change, add narration and visuals to demonstrate and invite students to problem solve, or present various problem solving strategies. Examples abound in sites such as Khan Academy or iTunes U, though some of these present non-interactive worked examples. Most screencasts are short 3-5 minutes' productions that focus on a single concept, sometimes followed by a quiz or other student-centered activity (Seery, 2010). A further advantage is that while online instruction relies on text and lacks paralinguistic cues such as voice intonation and a sense of social presence, screencasts have narration, often by an instructor and this adds personalisation and audiovisual stimulation (Matheison, 2012). The model of screencasting as an information dump to be accessed and digested is not considered to be pedagogically sound, and instructional design of screencasts needs to ensure that it engages students and provides scope for activity.

Literature review on screencasting in mathematics education

The computer and library science fields were early adopters of screencasting, but educators and researchers later recognized the potential applications of screencasting to online education (Peterson 2007; Sugar et al, 2010). Screencasts allow instructors to model behaviours and display operations and allow learners to view the content multiple times at their convenience (Sugar et al, 2010). In addition, there is a wide variety of screencasting software available, much of it free (Yee & Hargis 2010), and creating screencasts is fast and easy. Recent research has identified a need for more research on how to design mathematical screencasts that focus on student engagement, and that more generally take into account best practice in instructional design (Galligan et al., 2010), as most literature on the effectiveness of screencasting in higher education is limited to investigations of student's perceptions and their use of the recordings. Sugar et al (2010) have undertaken an analysis of common structural elements and instructional strategies in screencasts that support their discussion of the anatomy of a screencast. However, it is questionable whether their findings would be applicable to the design of mathematical screencasts that aim to support problem solving.

An overview of the podcasting literature may be found in (Heilesen, 2010), suggesting that positive outcomes may sometimes be achieved not by the technology itself, but when the technology supports approaches such as active learning or revision of concepts that are known to improve student learning. Heilesen recognises that screencasting “has opened up for new ways of integrating classroom teaching and net-based learning on the basis of pedagogical concerns rather than mere administrative convenience”. (Sutton-Brady et al, 2009) emphasise the need to focus on pedagogical design when producing short screencasts targeting individual topics to distinguish them from a repeat of lecture content. For example, screencasts may be designed to allow students to personalise their learning, listen at their own pace, and to highlight important information. Oud (2009) provides guidelines for the production of effective online screencasts, in a library instruction context and investigates software-walkthrough screencasts that show how to perform searches on the Web. She also argues that screencasts should contain a level of interactivity, e.g. control over pace such as pausing and fast forwarding. Although research on screencasting in the online environment is still emerging, there is preliminary evidence that screencasts may improve learning (Evans, 2011) and evidence in the mathematical context (Jordan et al, 2012; Loch et al, 2014).

In teaching students mathematical concepts, mathscasts aim to capture the progressive steps towards the solution of a problem. By doing this in a visual multimodal format, the mathscast acts as a form of scaffolding, reaching students' zones of understanding. Mullamphy et al (2010) concluded that screencasts capturing narration and mathematical handwriting on a computer were more engaging than a video recording of writing on a blackboard, a narrated PowerPoint recording or audio-only podcasts.

Beyond empowering students to learn complex concepts in a flexible, self-paced manner, the current research sought students' feedback on aspects of their learning experience in accessing and using mathscasts. Research has indicated that gaps in students' knowledge are often drivers for learning, and that for learning support to be optimally effective it needs to relate to learner interests, goals and strategies (Dron, 2007). For this reason, it is important that the screencasts target problematic, or threshold concepts that students need in order to advance their knowledge, of "troublesome knowledge" in mathematics (Loch & McLoughlin, 2012).

Pedagogical design of screencasts: Rationale and context for this study

By accessing video based instruction that combines multiple media formats, students can choose when and how often to access the mathscasts, and it is expected that enhanced motivation and positive learning outcomes will be achieved. Nevertheless, the instructional format of most screencasts has often relied upon a didactic model of pedagogy, and typically follows a well-established pattern of teacher demonstration, worked examples followed by student practice. Even in lectures, direct student interaction is limited due to the need for time-efficient delivery of content to large numbers of students. Instruction tends not to make use of technological interactivity and often does not intentionally include scaffolds to ensure the active engagement and participation of the learner. In short, pedagogically driven design of screencasts for deep conceptual understanding has been limited in the literature, and screencasts do not typically involve interaction or activity on the part of the student. The learning paradigm tends to be quite teacher-centred, with students as viewers rather than active participants.

When learning complex and abstract concepts and problem solving, learner support is often crucial, as it is in the case of mathematical concepts and logical reasoning skills. This has been recognised widely in Australia, where most universities offer mathematics support to their students in the form of face-to-face help from a tutor in a dedicated support space, during certain hours (Oliver & Goerke, 2007). Students today often work part time while also studying, and they rely on mobile devices and technology mediated tools for learning off-campus. They also seek more flexibility and choice in the place and pace of their learning, so there is growing demand for virtual, self-paced access to learning. Many first year students entering the sciences and related disciplines such as engineering need a strong foundation in mathematics thinking, and they often seek assistance in their first year of study if mathematics is not their major field.

To provide such more flexible options accessible around the clock and from anywhere with connection to the web, several maths support centres in Australia produce short screencasts for students to access online. Topics recorded range from the revision of prerequisites at middle to higher high school level, transition that some students may be missing, up to second year university level mathematics currently taught in engineering mathematics units and that students struggle with regularly. A particular collection of these screencasts of mathematical concepts and skills, labeled "MathsCasts", is produced collaboratively by the mathematics support centres at The University of Limerick (Ireland) and Loughborough University (UK) (Loch et al, 2012). The MathsCasts are usually of 5-10 minutes' duration, intentionally kept short to focus the learner's attention on one particular concept or problem, whilst showing all steps in the derivation of a solution. More than 400 MathsCasts covering first and second year mathematics are available as open educational resources, carrying a creative commons license (MathsCasts, 2016). These MathsCasts and other mathematical screencasts are also available on iTunes U and YouTube. Therefore technology supported instruction is now readily available for most universities in Australia where maths support centres provide academic assistance to students. The MathsCasts discussed in this study were developed and delivered at Swinburne University through the Maths and Statistics Help (MASH) Centre.

To address the issue of passive learning, the current project considered several instructional design approaches, based on self-regulated learning (SRL) theory, in order to foster and enhance active learning and develop students' engagements in understanding complex mathematical concepts. The primary goal of the work has been to support active students' cognition as they seek to understand abstract concepts. In addition to the lack of clear guidelines on how to design effective mathematical screencasts, there is little evidence of how students integrate these videos with their study, how often they view them and with whom, and what device they use to view them.

Research questions and methodology

Knowledge of student practices in relation to student use of MathsCasts can inform how these resources are created. While access to flexible learning may benefit student learning, there remain several areas that require investigation.

To inform design consideration for MathsCasts, the following research questions were asked:

1. What active learning strategies do students employ while interacting with the videos?
2. How important is the flexibility of the videos for learners, what devices are used to view the videos and, where are they watched?
3. How do students integrate MathsCasts into their studies to help them with mathematical knowledge and skills?

Student perceptions of the MathsCasts and their impact was assessed by surveying students about their experiences. As evidence of learning and study patterns, data is presented based on feedback that students have provided on how, where and when they watched MathsCasts. The researchers collected both quantitative and qualitative data to gather students' usage activities for the MathsCasts. A web-based survey was implemented at the end of the unit (Week 12), which collected students' demographic information, perceptions of value of screencasts, reporting of frequency of viewing, mode of viewing, perceptions of learning approaches used, and devices used to download the files. The survey was conducted anonymously, and 30 students participated. The data and analysis helped the researchers to answer the research questions mentioned above, including perceptions of learning supported by the Mathscasts, experiences in the various learning activities designed to help learning, and actual usage patterns. An online survey was issued to all students, asking a range of questions relating to their use of MathsCasts. Volunteer students enrolled in the first two engineering mathematics units responded to their use of the MathsCasts. Both units had sets of MathsCasts available that cover most topics taught, as well as prerequisite topics that students found challenging. The focus here was to elicit responses from students on issues such as how they watched the MathsCasts, duration of time for viewing and associated study strategies. Note that the university's learning management system did not provide reliable data on student access to the videos.

Results for research question 1: Active learning strategies

Students were asked an open-ended question "How do you watch MathsCasts?" The feedback (Table 2) indicates that students used the opportunity to skip forward to concentrate on sections of most relevance (33%), to control the video by pausing to think about an explanation (more than a third), but also to rewind and replay a section (>33%).

Table 2: How do you watch MathsCasts? (Multiple answers possible; n=30)

Answer Choice	Number of respondents (%)
I usually watch a complete MathsCast from start to end.	21 (70%)
I skip sections by fast-forwarding to concentrate on sections that are most helpful.	10 (33%)
I rewind to watch some sections again.	16 (53%)
I pause playback to think about an explanation.	11 (37%)
I pause playback before an explanation to attempt the maths myself.	7 (23%)
I watch an explanation then try the problem myself.	16 (53%)

Results indicate that there is active engagement with the MathsCasts. An impressive 70% watch the complete video, which shows that our concept of recording short (5-10 minutes), targeted videos is working. Students appreciate the control over the place, pace and the frequency of their individual use of the MathsCasts.

Results for question 2: flexibility of MathsCasts in supporting student learning

Participants were asked: “Where and when do you watch MathsCasts?” The responses (Table 3) confirmed expectations that students valued the flexibility of having mathematics support without setting foot on campus. One of the strong motivators for producing MathsCasts is to provide students with anywhere, anytime mathematics support, not limited to support centre opening hours (Loch et al, 2012). Students are clearly taking advantage of this flexibility to access help: Nearly 90% watch the videos when they are off campus. This finding is significant insofar as it indicates that flexible delivery of mathematics support through maths casts means that students are learning at their own pace, in any place. Nevertheless, we had an expectation that students would multi-task and that a greater number would view them while travelling. The majority of those accessing the videos when on campus are doing so from the library which provides computers for individual students as well as group study environments.

Table 3: Where and when do you watch MathsCasts? (Multiple answers possible; n=28)

Answer Choice	Number of respondents (%)
When I'm off campus.	25 (89%)
When I'm on campus.	9 (32%)
When I'm in the library on campus.	9 (32%)
When I'm travelling.	2 (7%)
While I'm eating.	3 (11%)
While I'm watching TV.	0 (0%)
While I'm listening to music.	4 (14%)

Results for research question 3: Integration of Mathscasts into personal study

Another question investigated student perceptions of the learning support via MathsCasts and the strategies used by students. To find out whether students used the MathsCasts strategically, we asked the question: “Please tell us about your use of MathsCasts” in order to gain insight into usage patterns and motivation. Table 4 shows that some students are selective as 70% watch only those MathsCasts that relate to topics they struggle with. They also take strategic approaches as some view MathsCasts when they are studying, others when they are working on assignments and some to prepare for a test.

Table 4: Comments on when, how & how often MathsCasts were accessed (Multiple answers possible; n=30)

Answer Choice	Number of responses (%)
I watch all MathsCasts that are made available for my unit.	10 (33%)
I watch only the MathsCasts on topics I find difficult to understand in my unit.	21 (70%)
I watch MathsCasts from other units if they cover topics relevant to my unit.	5 (17%)
I watch MathsCasts from other units out of interest.	3 (10%)
I watch MathsCasts when I'm studying.	15 (50%)
I watch MathsCasts to help me work out assignment problems.	20 (67%)
I watch MathsCasts before the topics are explained to me in lectures.	3 (10%)
I watch MathsCasts after lectures to see another explanation of working a problem.	11 (37%)
I watch MathsCasts when I prepare for a test.	16 (53%)
I watch some MathsCasts more than once.	19 (63%)
I watch MathsCasts together with other students.	1 (3%)
I watch MathsCasts by myself.	25 (83%)
I discuss the MathsCasts I've watched with other students.	4 (13%)

Over a third (37%) watch MathsCasts after lectures for a different explanation of how to work through, and solve a problem. Few respondents watch MathsCasts before lectures, indicating that they do not regard them as preparatory resources, but instead use them to review and revise concepts. Students tend to watch MathsCasts by themselves, with some viewing with other students or engaging in peer collaboration. Nearly two thirds of the students watch MathsCasts more than once, attesting to the perceived usefulness of these resources to support learning.

Discussion of results and limitations of the study

The results provide insights into students' learning modes and their reasons for accessing the mathscasts, with the majority viewing them more than once and most frequently to complete assignments. The majority of students select episodes that focus on competencies and topics that are either unknown to students or that need to be developed further. The MathsCasts episodes demonstrate how to deal with a problem and discuss strategies and possible solutions, only 37% of students watch them after class to review content and processes, and a smaller percentage watch the MathsCasts before class, as advance organisers. This indicated that students perceive MathsCasts as a useful resource when completing assessment tasks and revising unfamiliar problem solving strategies. This aspect of cognitive scaffolding could be addressed by the teacher inviting the students to participate in a practice task so that they apply the skills demonstrated.

There is evidence in the results that screencasts support independent learning, and enable students to study flexibly off campus. The results also affirm that students actively engage in mathematics tasks while they are viewing, with approximately a quarter of the students responding that they pause the video before watching an explanation, and more than half trying the problem themselves after watching. This shows that MathsCasts are not consumed passively as one would watch TV but are integrated into students' learning routines. In addition, students are quite strategic and focussed in the timing and purpose of their viewing, with the majority preferring to use them for assignment preparation, fine-tuning of their knowledge for tests and for review of complex topics.

No bold claims are being made for the results described here as the project was a small-scale exploratory study that yielded limited data. Nevertheless, the study provides baseline evidence that students accessed the resources at various times in order to revise or complete assessment tasks. They expressed the view that accessing the MathsCasts online to review concepts and procedures was a good complement to regular classroom work.

Conclusions and future research

In this study, we presented a case study of students' learning experiences and perceptions of supplementary mathematics support offered via screencasting. Overall, the results show that the students were positive about the impact of MathsCasts on their learning. They also appreciated the flexibility afforded by the screencasts, which enabled individual study and reflection on challenging concepts. The MathsCasts resources supplemented, but did not replace face-to-face lectures and support sessions. In addition, students valued the sense of freedom in being able to access the screencasts on demand, study anywhere and anytime, and view the screencasts in their own daily personal and professional settings. While there are strong arguments for the provision of screencasts for mathematical support, there is no guarantee that students will either access these or learn from them. It cannot be assumed that all students will have the skills to self-regulate their learning when presented with complex mathematical concepts. In applying a design based approach, we adopted several iterations at the initial design stage to produce screencasts that allowed students to access explanatory screencasts based on worked examples and we then progressed to developing instructional design models to enhance engagement of students with mathematics. Initial evaluation of student feedback indicates that the students who responded to the voluntary survey have the skills to include MathsCasts as active support resources into their study strategies.

The study builds on the work of research of Loch & McLoughlin, (2011) who have begun to develop a strategies to develop self-regulated skills among students with screencasts. These authors encourage more research to further explore development of mathematical competencies through instructionally interventions and how digital tools can be used to support students' interest in learning in STEM subjects.

Our research continues to investigate the optimum design principles for MathsCasts that are aimed to increase student understanding of complex mathematical procedures, and to scaffold students' comprehension of threshold and complex concepts and problem solving in mathematics. This research provides evidence of active student engagement with MathsCasts and demonstrates that MathsCasts can act as cognitive bridges to extend understanding and develop mathematical competencies.

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