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BUILDING BLOCKS: AN INTERDISCIPLINARY APPROACH TO THE DESIGN AND PRODUCTION OF STOP-MOTION LEGO® ANIMATIONS FOR UNIVERSITY MATHEMATICS

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Abstract

University mathematics is notoriously abstract, making it challenging for students to visualise concepts and build mental models. Traditional teaching methods often rely on two-dimensional diagrams coupled with arm waving from the lecturer to represent complicated three-dimensional systems. These techniques have limited success in face-to-face settings and even less effectiveness in online teaching and learning.

During the extensive lockdowns of 2020-2021, a mathematician and aspiring animator used the time to create a series of stop-motion LEGO® animations. The animations aimed to help science and engineering students convert word problems into formal mathematics, to visualise abstract concepts and to illustrate complicated mathematical processes involving multiple steps, which are challenging to convey through static representations.

Using an action research methodology, this paper examines how working in an interdisciplinary team with animation students affected the process, development and production quality of three new maths focused LEGO® animations. Reflective examination was used to draw out insights, highlighting learnings from the animation processes including the impact of interdisciplinary collaboration on narrative focus and production quality. Key findings focus on the need to establish common goals and to find a bridging language that supports communication between experts in different disciplines.

Keywords: Maths; Education; Animation; LEGO®; Interdisciplinary; University.

Introduction

Mathematics is widely perceived as a difficult subject, and even students who have chosen to study for degrees such as science and engineering often struggle with higher level mathematics. First-year university maths units with their high drop-out and failure rates are often described as 'gatekeeper' subjects, guarding the entry to STEM courses and keeping out potential students (Gasiewski et al., 2012). Some of the challenges faced by students attempting such gatekeeper subjects include difficulty visualising abstract concepts and three-dimensional systems (Sorby, 2007), translating word problems into diagrams and mathematical notation (Verschaffel, 2020), and working through processes that are not read from left to right as simple calculations do in lower-level maths (Strogatz, 2019). STEM subjects such as mathematics are also often taught with very traditional teacher-centred pedagogies and lack creativity in content delivery (Pollard et al., 2017).

Animation has been shown to help students bridge the gap between physical situations and abstract concepts. For example, in a meta-analysis of literature comparing learning from static representations and animations, Berney and Bétrancourt (2016) found studying with animated visualisations yielded higher learning gains than studying with static graphics, particularly for the natural sciences. However, these learning gains depend on how key learning points are signposted with visual and auditory cues (Mayer & Moreno, 2003) and to what extent the animation is used to enhance the mathematical content rather than just providing extraneous decoration (Ploetzner & Lowe, 2012).

During the long periods of lockdown experienced as part of the COVID-19 global pandemic, Emily explored these concepts via the creation and implementation of instructional animations that aimed to support students learning algebra. Positive feedback received from mathematics students in the class they were first implemented in led to the development of *Brick Maths*, an animation project and the subject of this paper's case study.

From humble beginnings: Algebra and animation

The pandemic necessitated university classes undergo a rapid unplanned pivot to online teaching (Nordman et al., 2020). Based in Melbourne, Australia, the authors experienced one of the longest and strictest lockdown periods globally (McReadie, 2022). This led to an excess of indoor spare time that saw Emily rediscover the joys of LEGO® and the new discovery of a phone app called *Stop Motion Studio* that promised to produce stop-motion animations quickly and easily. She first adopted LEGO® stop-motion animation as a fun hobby to pass the time before realising its potential to communicate some of the more complex mathematical concepts in the undergraduate class *linear algebra and applications* which she was preparing to teach for the first time. This first-year class was compulsory for students majoring in mathematics, physics and engineering and historically had been a challenging class for students to pass. The class also served as a pre-requisite for several higher-level classes and thus was a hurdle students must overcome to progress in their degrees.

Some of the challenging topics embedded within this class included *matrices*, which are arrays of elements (usually numbers) arranged in rows and columns. Processes involving matrices, such as multiplying two matrices together, require many calculations. Multiplying matrices is an example of a process that does not involve steps that go from left to right, thus is challenging to explain through static representations and text. Another topic is *vectors*, which in maths and physics are quantities with both magnitude and direction. Interestingly, this concept made an appearance within the popular animated feature *Despicable Me* (Renaud & Coffin,

2010) where the antagonist Vector claimed to commit crime with both direction and magnitude! Vectors are represented by arrows whose lengths are proportional to their magnitudes and represent quantities such as forces and velocities. Students often struggle with interpreting word problems containing vectors, for example, a duck is facing south and swimming at 2.5 km/hr in a river flowing westwards at 5 km/hr. What direction does the duck swim in? Another challenging topic is curves and curvature, which involves plotting polar graphs and representing spheres, cones and cylinders in different coordinate systems. *Complex numbers* are the final challenging topic discussed in the class. These involve dealing with both real and imaginary numbers, where imaginary numbers are expressed in terms of the square root of negative one and are challenging to students as they struggle to visualise something "imaginary".

Particular challenges faced in teaching these concepts online were engaging students in calculation heavy material during a time of forced online learning and lockdown fatigue, and describing three-dimensional systems with only a two-dimensional screen to communicate through, losing the ability to wave arms and use physical models as would traditionally happen within the classroom. As noted earlier, Emily had started playing with LEGO® and stop-motion animation as a fun project to pass time, but when preparing lessons specifically for online delivery she had a moment of inspiration – that a LEGO® base plate looked very similar to a mathematical matrix, as shown Figure 1.

This led to the next idea, that the usually tedious process of multiplying matrices, which requires many calculations performed by rows and columns, could be represented with plates and dots, illustrating the multiple steps of the process without getting bogged down in numbers and sums. Figure 2 shows a sample of the initial animation that was accompanied by some light jazz. It was embedded within in a lecture following the numerical example to reinforce the process.

Knowing that science and engineering students are often big LEGO® fans (Boulter et al., 2022), this novel approach to teaching mathematics proved popular both in terms of student learning and enjoyment. This initial success prompted the creation of further stop-motion content for the linear algebra class. For this, Emily built a low-budget animation studio in her garage and created a series of 1-to-3-minute animations using Adobe Rush (Cook, 2022). The topics explored included vectors, complex numbers, 2D and 3D coordinate

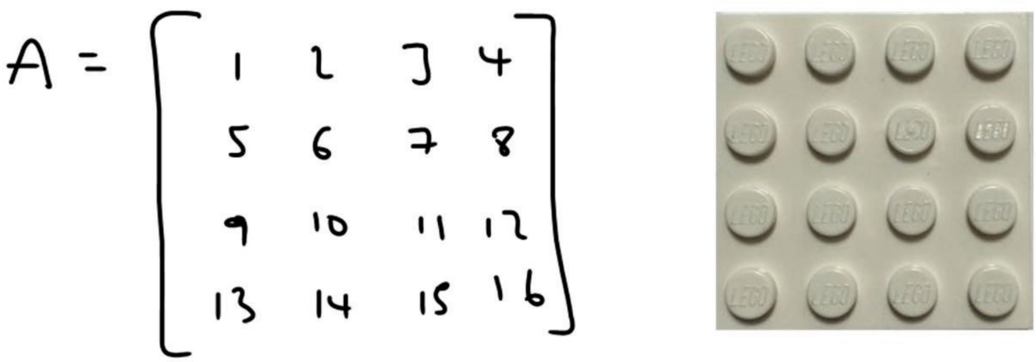


Fig. 1 Shows a comparison of a matrix (left) and a LEGO® baseplate (right). This was the original inspiration for the Brick Maths project using LEGO® and stop-motion animation to teach maths.

systems and linear transformations. Collectively these animations, branded *Brick Maths*, were embedded throughout mathematics classes and shared with the public on YouTube.

With a background in physics, Emily conceived and crafted these animations without formal training in animation theory or practice, relying solely on instinct and equipment that was readily available from local stores during lockdown. While these initial creations lacked finesse, they inadvertently embodied the characteristics outlined by Wells (1998) for what he terms orthodox animation, incorporating elements such as configuration, specific continuity, narrative form, evolution of context, unity of style and dynamics of dialogue. Additionally, the animations subtly delved into the realm of what Wells referrers to as experimental animation by introducing elements of the artist's presence through narration and character, and by embracing the concept of construction (Husbands & Rudell, 2018) through the intentional crafting of scenarios that would otherwise be unattainable within the confines of a physical environment such as a classroom or an office space.

Though it is unclear what, if any, of these characteristics played a key role in facilitating student learning and engagement, anecdotally the animations proved popular with students who appreciated the elements of fun not often associated with higher-level mathematical learning. This sentiment was echoed in the anonymised official feedback from the class's student survey in answer to the question "what did you like most about this unit?"

> The LEGO videos help visualise the problems really well.
>
> She did a great job in making the LEGO videos; these were funny and a great introduction to concepts.
>
> I liked the Lego videos they helped some of the concepts stick in my mind.

For this initial phase of this project, student feedback highlighted the perceived value of the animations in explaining and clarifying concepts, making ideas memorable and bringing an element of enjoyment to the learning process. However, the production quality suffered due to issues of inconsistent lighting, poor sound quality and a lack of post-production which are understandable shortcomings given Emily's limited animation knowledge, experience, and access to equipment.

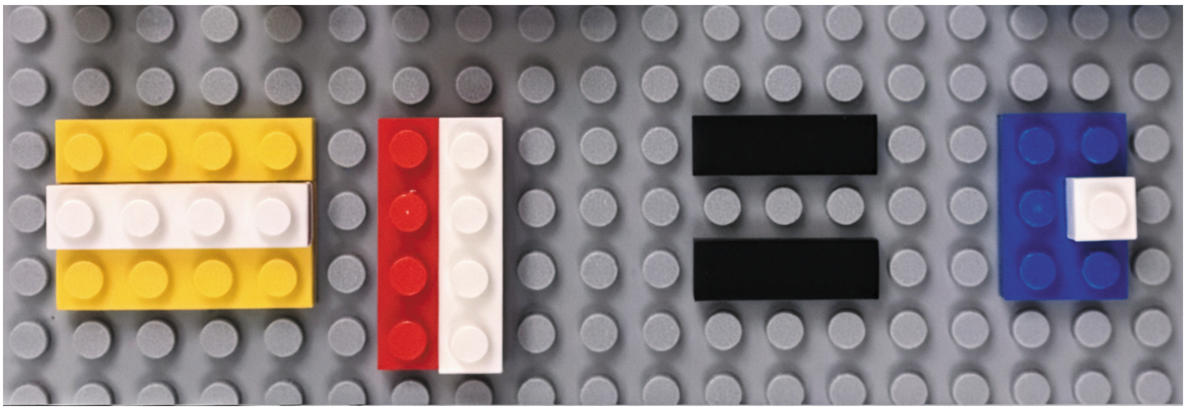


Fig. 2 A still from the initial LEGO® stop-motion animation titled *Matrix Multiplication* (2021) demonstrates the use of LEGO® base plates to illustrate the process of matrix multiplication.

Improving practice through action research

The next iteration of the *Brick Maths* project employed an action research methodology (Altrichter et al., 2002) with the primary objective being to improve production quality while preserving the narrative structure and stylistic elements of Emily's initial animations. Working in collaboration, Emily and Steven developed a plan of inquiry that aimed to improve Emily's own work and the prospect of bettering student learning when implemented as class resources (Kember & Gow, 1992), though the latter is beyond the scope of this paper.

The first phase of this plan saw Emily independently write three scripts, following the same processes and maintaining the same standards embodied within her initial animations.

The second phase involved sourcing and assembling an animation team with the necessary knowledge, and skills to produce films of a higher production quality.

The third phase focused on data collection, where semi-structured interviews were conducted by Steven with the animation team upon completion of the project. Serving as a 'critical friend' to all (Kember et al., 1997), he was able to probe and document insights into the animators' own practices, processes and experiences working as a member of an interdisciplinary animation team. Interview questions were designed to encourage individual critical reflection in preparation for sharing insights publicly and concerned: the individual's prior knowledge and experience with animation projects and interdisciplinary teams, their motivations for participating in the project, their expectations versus the realities of their role, the key challenges and successes encountered while collaborating as part of an interdisciplinary team, and advice they would offer to others working on similar projects in the future.

The following sections of this paper leverage these interviews and the authors' critical examination of their work to reflect on actions taken and lessons learned throughout the project.

Enter the animators

The animation team comprised Emily and six undergraduate animation students, including Marianne, Drew and Fiona, collectively referred to as *the animators*. Aside from Emily, the animators had all recently completed their first year of a Bachelors' degree in animation that included subjects in 2D animation practices, animation principles, storyboarding, and a six-week introduction to stop-motion animation. Based on her engagement with this introductory stop-motion animation class, Marianne was invited to participate in the *Brick Maths* project. Drew and Fiona along with the other animators were recruited through Marianne's peer network.

To establish the base level of knowledge and experience at the start of the project, it is important to note that the introductory stop-motion animation class familiarised students with various stop-motion techniques, essential workflows, the basics of the Dragonframe animation software, and the application of animation principles within a physical three-dimensional environment. This class also specifically prohibited the use of LEGO® as an animation material. The intent of this was to increase students' awareness of and safety working with pliable materials, adhesives, hand tools, and to avoid the limitations of movement that interlocking bricks instinctively encourage. The class's lessons were designed to be completed in a matter of hours, with animation outputs ranging between 5-10 seconds in duration. Each involved scenario-based performances using simple volumes made from wood, plasticine and string to more complex handmade puppets. Lessons also introduced students to basic post-production techniques that focused on rig-removal, creating text and graphic overlays, and non-linear editing techniques using Adobe Premiere Pro.

Steven pitched the project to the animators as an extra curricula project to be completed during their summer break. At the time it was assumed they would be working from a single developed script, a basic storyboard, and be directed by

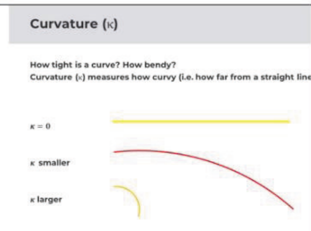
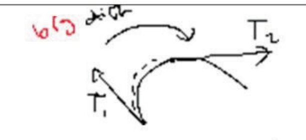
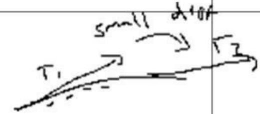
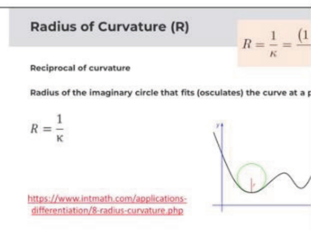
	Graphics from my lectures	Animation Ideas
Just how curvy is a curve?		
To measure the curviness of a curve we use a property called curvature, which is represented by the Greek letter kappa.		
If kappa equals zero, curvature is nothing, so it is not curving and what you have is a straight line If kappa is small, the curve deviates a little from a straight line, If kappa is big the curve bends a lot more.		Could use roller coaster, straight section, gentle curve, big curve and people screaming. Take "photos" at points Include squirrel at some point?
In more formal mathematics the curvature is the rate of change of the unit tangent vector T with respect to arc length, s going along the curve	$\kappa = \left\lvert \frac{d\vec{T}}{ds} \right\rvert$	whiteboard
so kappa is big if as you move along the curve the tangent changes a lot,		
and kappa is small if, as you move along the curve, the tangent vector keeps pointing in much the same direction.		
Another property we can use is the reciprocal of curvature, which means calculating 1 divided by kappa. This property of the curve is called the radius of curvature, and at a point gives the radius of the circle that osculates the curve.		https://www.intmath.com/applications-differentiation/8-radius-curvature.php -scroll down for the exploration. How on earth do you do that with lego?

Fig. 3 A sample of the script and storyboard initially produced by Emily for the animation titled *Curvature (with a squirrel)* (2024).

Emily as the client and overarching producer. However, these expectations quickly shifted once the team had assembled and engaged in collaborative discourse regarding not one, but three scripts Emily had developed. All scripts were of a comparable level to those developed in the initial days of the *Brick Maths* project. By the nature of Emily's disciplinary background and being a novice auteur garage-studio animator, the scripts were written and presented in tabular form with supporting notes that included samples of graphics pulled from her lecture slides and rough ideas of how they could be animated (see Figure 3).

The three scripts featured textbook scenarios and examples commonly used in mathematics education. Transforming these into a new form, Emily had thought deeply about the impact of her previous films and the project at large, developing a set of guiding principles that required each film to include:

i) correct mathematics with no shortcuts or dumbing down for the target audience of tertiary level science and engineering students,
ii) the concepts must be visualised using physical models,
iii) calculations must be handwritten and shown on a whiteboard accompanied by a LEGO® version of Emily as the lecturer (see Figure 4), and
iv) an animal-based joke must be included at the end, leaving the audience with a good vibe and making mathematics fun.

During early meetings of the team, the animators worked collaboratively to develop and pitch rough storyboards of the provided scripts, incorporating their own creative ideas and efficiencies that included the use of consistent storytelling worlds and models that belonged in those environments. Emily provided feedback and selected ideas that that showed potential to visualise the mathematics concepts, refining the scripts as necessary.

The following three cases provide a reflective examination (Cowan, 1998) of the interdisciplinary workflows that shaped the development and production qualities of each animation. The first case delves into the film titled *The History of Pi (with a tiger)* and explores the fine line between precise mathematical communication and aesthetic considerations. This is followed by an analysis of the film *Tangents and Derivatives (with cats)*, which emphasises the challenges encountered when conveying complex mathematical concepts while maintaining focus within the storytelling world. The third case examines the making of *Curvature (with a squirrel)* which commenced midway through the production of the other animations and ultimately benefitted from insights and lessons learned from those to achieve a greater balance between accurate mathematics and production quality.

The History of Pi (with a tiger)

The purpose of this film was to highlight that many mathematicians have worked on understanding the number Pi, (the ratio of a circle's circumference to its diameter), and the processes they used to do this. The historical journey spans thousands of years and involves numerous significant mathematicians. After the initial meeting of the animators,

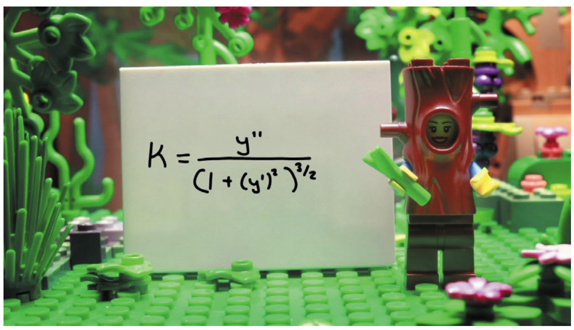


Fig. 4 An example of communicating mathematical workings with handwritten maths superimposed on a scene-based whiteboard, from *Curvature (with a squirrel)* (2024).

Marianne stepped forward to take the creative lead of this animation. She brought skills in effective communication and teamwork gained from earlier studies in communication design and involvement in creative projects where she had learned the importance of prioritising client wishes over her own creative pursuits, and the enjoyment of the dynamic exchange among creatives and its enhancement of project outcomes. When communicating with Emily as both the client and producer, Marianne was able to draw upon a strong foundation and range of tools that included:

Visual communication.

Drawing upon her background in design, Marianne was confident in her capacity to convey ideas visually through illustrated storyboards and diagrams. This talent facilitated the visualisation of the script and its concepts into storyboards and then an animatic, which enabled Emily to understand Marianne's creative vision without the need for a deep understanding of animation practice and process.

Being able to communicate visually to each other was seen as an important first step in being able to effectively convey math concepts to broader audiences. This way of thinking and practice led to the development of new perspectives of how concepts could be better communicated using LEGO®, while also leveraging the unique characteristics of animation. Marianne recalls an example of this in reference to Figure 5 that explains how Archimedes estimated the circumference of a circle using inscribed shapes.

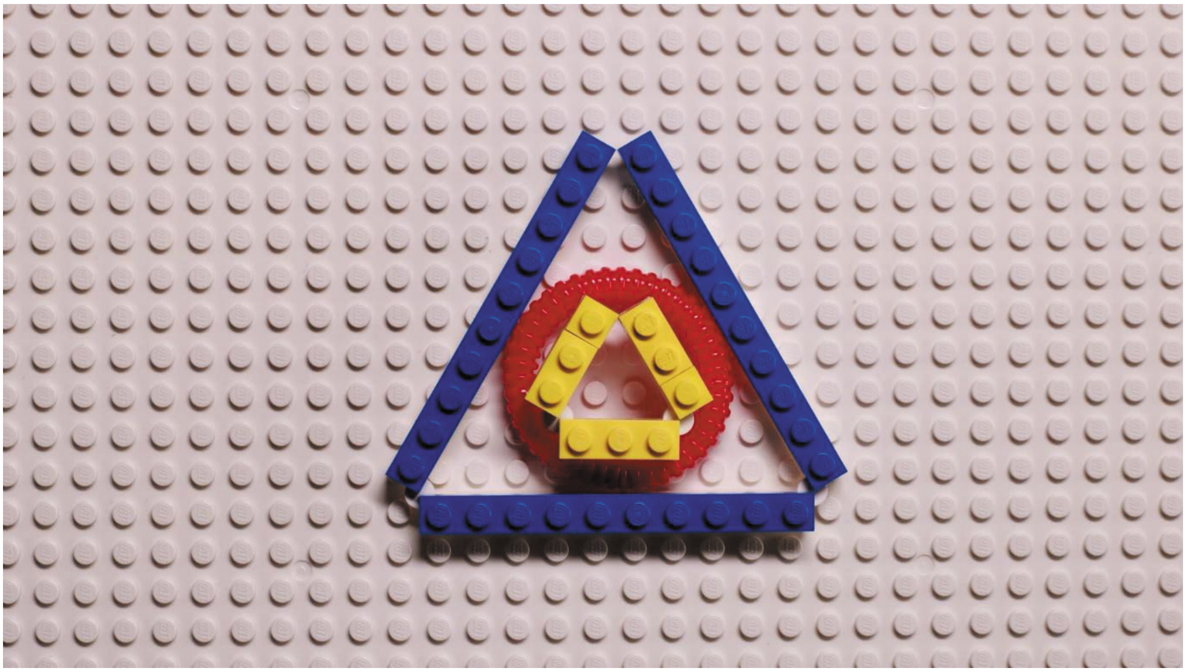


Fig. 5 A still from the animation *The History of Pi (with a tiger) (2024)*. While it may appear as ordinary LEGO®, closer inspection reveals how leveraging animation the 'model' was able to break away from the physical constraints of interlocking bricks to include overlapping and movement to visually communicate this method of estimating a circle's circumference.

> When it came to the math components in the film, Emily and I did go back and forth as how to best communicate them visually. For example, there was one moment in the script that explained how drawing a shape around a circle and then another similar shape within that circle can be used to calculate the circle's perimeter. By exploring this visually we were able to find interesting ways to show this using both LEGO® and animation. Ultimately Emily came with the concept of the triangles and the circle, and I came up with the concept of using LEGO® pieces and animating them instead of creating a chalk drawing on a blackboard.

Bridging language.

Though she is based within a university mathematics department, Emily has an undergraduate degree in physics and often self-identifies as a physicist rather than a mathematician. Physics and animation have many commonalities in terms of modelling motion and Marianne was able to utilise this connection to find a common language when describing what she was doing, and when offering advice to Emily when she herself animated some of the animation's simpler scenes.

> Early on there were things like having to explain animation concepts like timing and I found myself explaining it in physics terms, so she gets it… for example, the acceleration and deceleration – ease in and ease out. I would go this is basically the same thing as acceleration. And she would go 'ah yes that makes sense because that's what happens in physics'.

Employing a bridging language was essential in overcoming the divide that existed between the team's diverse knowledge domains and languages. Emily also reflected on this need to find a common language in order to reconcile the overlap and differences between the language used in animation and physics.

> There were a lot of things the students said that, at first, I thought I didn't understand, but as they explained and I learned more I realised were just different ways of saying the same things. So, timing and arcs - for them, were animation principles and basic stuff all animators should know. For me, they are the equations of motion that I learned as basic physics. We just talked about them differently, and they tended to do things by feel, whereas I calculated things and had spreadsheets with timings and stuff worked out. But they are exactly the same ideas.

Over time, a common vocabulary was developed that encompassed animation and physics terms, with a slight leaning towards adopting animation terminology. This was due to Emily having an interest in learning animation, whereas none of the other authors had any particular interest in physics or mathematics.

Verbal exchange.

Despite being the client and producer, Emily was also hands-on throughout the production process, actively participating in the construction of sets and the animation of assets rather than simply providing a script and directives for its execution. Her presence in the animation studio was frequent, offering insights and answering queries as they emerged. However, she typically refrained from intervening in the animators' creative processes unless she had concerns about the accuracy of a concept's visualisation. As Marianne describes below, she felt this approach didn't have a huge impact on her work as the focus of the animation was primarily on the history of Pi rather than the math itself.

Fig. 6 This still frame from the film *The History of Pi (with a tiger)* demonstrates the intricate details of the set's design and tension between the visualisation of the math concept and the overall aesthetic that had been created.

> When the math in the other films wasn't accurate, Emily would say something like 'oh ok this isn't quite accurate, this is how it actually goes'; however, with Pi her feedback was more along the line of 'this could be a little bit more simplified or actually the history was a bit closer to this'. This usually led both of us down a path of creative discussion in front of the set or monitor, talking about why I chose a particular creative direction.

This combination of visual communication, finding a common vocabulary and being open to back-and forth feedback was helpful in progressing the film through the stages of the stop-motion animation pipeline. However, there still had to be an end point beyond which Marianne and Emily reached the limit of their shared understanding. As Marianne explains, there were maths concepts that needed to be addressed by Emily.

> When it came to visualising the maths if it got too complex, I would often fall back to the idea of using the Emily mini-figure showing a formula on a whiteboard. I wasn't super ambitious in terms of visualising the mathematics and relied on Emily to come up with the solutions in that regard, perhaps because it was beyond my comfort zone. For example, there were scenes that I kept blank in the animatic as a work-in-progress. This was because I wasn't sure of the best way to visualise a concept and that's where I would seek input from Emily as the math expert.

For Emily, the wall was hit when moving through the pipeline from production to post-production where she had absolutely no knowledge of the programs or workflows Marianne was employing. According to Marianne when she needed to explain concepts like masking, compositing, colour grading or exporting compositions from After Effects, Emily would openly take a step back and leave it to her.

When thinking about what advice Marianne would give to others attempting a similar project in the future, her key message was to simplify as much as possible. The combination of student animators with grand ambitions, working with an interdisciplinary collaborator with little sense of project scale, time requirements or efficient animation techniques, meant many activities took far longer than necessary and several shots were more elaborate than they needed to be. Marianne describes this using an example of the scene shown in Figure 6.

> There was one particular set depicting an outdoor location in China, where the story focused on the mathematician Zu Chongzhi, who worked out the first seven digits of Pi by making a shape that was basically a circle due to how many points it had. I thought I could incorporate that into a Moongate or something similar that belonged within the environment, again thinking of how to keep the concept visual. Had I gone for a whiteboard solution for that scene, it probably would have been the wrong decision. This is because I had already used the whiteboard in previous shots, and it would have made the visual narrative a bit repetitive and not achieved Emily's goal of making maths visual. On reflection, there would have been simpler ways to visualise this moment that didn't require such an elaborate and time-consuming set to build. Some of the most challenging things about this scene was that it required a lot of studio lighting and that it featured a fairly intrusive camera. These limited the physical space I had to work in and made it difficult to take care of all the foliage in the scene. It could have been a much simpler set, perhaps something indoors or a smaller hero asset that still signposted the location as being within China. As much as I love the look and animation within that scene, it was a nightmare.

Emily recalls being wowed by the strong visuals Marianne had incorporated into the storyboards, and by the creative ideas and on-set beauty she had fused into the film, particularly given the script included locations from ancient Greece and China to Wales and even space. The downside of this was that the scale of the historical scenes led to a massive blow out in terms of time, both to build the elaborate sets and to film the shots which often required the complexity of camera motion. There is also a stark contrast in terms of the set design and aesthetic choices between the historical scenes as shown in Figure 6 and the mathematical scenes as seen in Figure 5. At the time of writing, the final animation of *History of Pi (with a tiger)* had not been finalised and published. However, a teaser showcasing some of the concepts discussed can be found on YouTube (History of Pi, 2023).

Tangents and Derivatives (with cats)

Derivatives are the first topic covered in most calculus classes and necessitate a big conceptual jump for most maths students (Thompson & Harel, 2021). As such, this film was challenging to create due to the difficulty of the mathematics needing to be covered, and how these concepts would be best explained to facilitate student learning.

Unlike the previous film, Emily came to this project with a clear visual example in mind of using an off the shelf LEGO® roller coaster to explain the steepness of lines. She was able to hand over a script and rough sketches of how a roller coaster could be used to explain some aspects of the maths to Drew, the creative lead for this animation, who was studying a double major in animation and games design. The tension between visual creativity and clarity of maths in this film was a significant issue throughout production. Both Emily and Drew were able to recall examples of where they had to 'pull back' to prevent the maths getting lost, and to balance the difficulty of the mathematical examples and how they were presented.

The first instance of this tension involved lighting and filming the scene shown in Figure 7, which led to an interesting but critical conversation about who or what needed to be the star of the shot. As a maths academic, Emily pretentiously called the red line indicating the tangent to the curve at a point along the roller coaster track the 'eponymous hero' of the film. However, Drew had set up the lighting and camera focus to draw attention to the characters on the rollercoaster as they passed by, as he explains:

> There are several moments that feature fun little characters on the roller coaster and as they ride show lines that are a tangent. But they seek a lot of visual attention because they are fun and interesting characters zipping around on what should be a relatable experience for many viewers.

From a maths perspective, the LEGO® characters were only used for context and decoration to remind viewers what steep and shallow slopes looked and felt like, but the red tangent line needed to be the focal point of the scene as the key learning objective of the video was about tangents.

The second example of needing to pull back relates to the scene shown in Figure 8, where a character riding a merry-go-round drops an ice cream that flies off along a tangent line to the curve at the point at which it was dropped. Emily's teaching experience highlights this concept as a major misconception for many students in maths and physics, who often assume the dropped object would follow a curved path rather than a straight line. Drew explains that he had conflicting feelings about the creative execution of this scene but notes the final cut very much did the job it needed to do.

Fig. 7 Shows the competing nature of the red tangent line and the characters riding the rollercoaster in *Tangents and Derivatives (with cats)* (2024). This scenario highlighted the need to pull back the creative focus on the riders to ensure the mathematical concept (the tangent line) remained the star of the shot.

> I believe we pulled back just enough to strike the right balance between creativity and clear communication. In some places it might have been a little too much, for example when we moved from an eye-level view to a top-down view the creative was very simple. I do feel like it could have been a bit more visual, but that's just my creative brain wanting to add more. The top-down view does create a nice solid representation of the concept; it's not too busy, so it shouldn't distract the viewers. As an animator, this scene symbolised my internal struggle between adding creative flair and adhering strictly to the essential elements and goal of explaining the math concept.

Conversely, Emily was ecstatic with the outcome of this scene. Had she been working in isolation it's likely she would have chosen to visualise this concept using the classic textbook example of a discus thrower releasing the discus, and the discus following a straight-line path if viewed from above. However, by listening to and working with Drew on his perspectives of narrative and world design, a more consistent story was found by incorporating a merry-go-round into the theme park world.

The third example highlights the balancing act between communicating math concepts and having rich visuals. The formal 'whiteboard' scenes aimed to make a clear link between the real-world examples shown throughout the film back to the maths presented in the way students will see it in their lectures and textbooks. As Drew explains below, he agreed with making the distinction between the formal and the more imaginative scenes.

> I specifically limited the whiteboard scene to just the math. This allowed me to be more creative over the other scenes where I was visualising what the Emily mini-figure was talking about. The challenge was in the fact that mathematics is inherently objective, you either know the equations or you don't. I was crafting visualisations to illustrate what's being discussed, which ultimately converge with the black-and-white nature of formulas like X times Y equals Z. I believe it all harmonises, the visual elements complement the formulas because, at its core, the narrative is about those formulas and the practical examples that bring them to life. That's what makes understanding the math easier – having those visual representations. Otherwise, it's just abstract symbols on a whiteboard, and you wouldn't need to use animation for that.

Emily was also conflicted with this aspect of the film, particularly with one example towards the end that explains how to

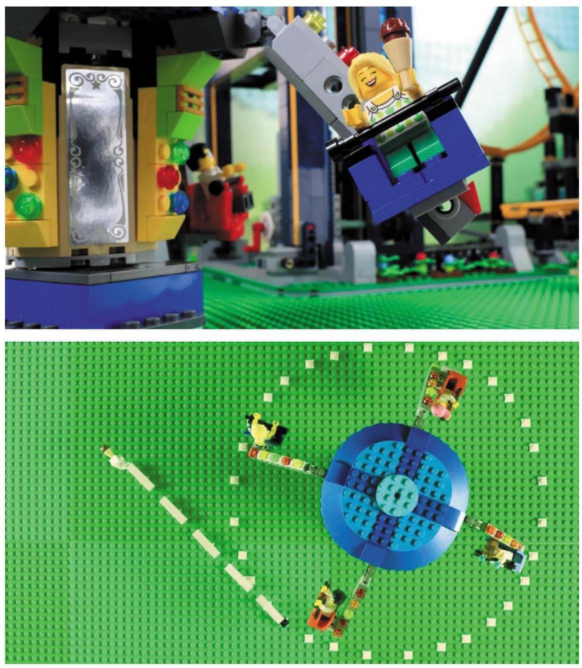


Fig. 8 Features two shots from the merry-go-round scene from *Tangents and Derivatives (with cats)* (2024). The first (top) is a more cinematically interesting shot that was followed by a top-down simplified version (bottom) that prioritised the visualisation of the math concept.

calculate the derivative from first principles. The calculations are complicated, even with the most basic example, and she was unsure whether to include it or not. However, through verbal exchange and working to resolve this dilemma, Drew was able to create a mix of whiteboard calculations and a LEGO® graph using post-production techniques. This approach appears to strike the intended balance of math communication. But, as Emily had said throughout the project,

> It is still a bit confusing, but I suppose it just *IS* confusing. If it wasn't, then I wouldn't need a roller coaster and a team of animators to help me explain it!

Coming into the project Drew had worked with other creatives, however lacked experience working with and for someone like Emily who was coming from a traditionally 'non-creative' discipline. This saw Drew employ a casual communication style with Emily and draw upon professional animation tools like storyboards and animatics to bridge the knowledge and language gap that existed between their disciplines. As he explains below, this ultimately facilitated open and collaborative discussion around the maths and animation ideas within the film.

> Emily came to me with her script with an expectation of its duration. My first contribution was to read the script and visualise the scenes in the form of 10 to 30 second-long storyboard panels. Being able to bounce ideas back and forth with her at this stage of the project set a positive and productive tone of how we were going to work together. As this process of review and refinement continued, I'd gradually transform the storyboard into an animatic and we'd engage in the same process to finesse them until we were both happy.
>
> Throughout this project I discovered I'm more of a visual communicator, which helped in the overall process because I could explain different thoughts to her in a creative and collaborative way. So, when I needed Emily's expertise for scenes heavily reliant on maths equations, she was very much able to lean into similar creative approaches to explain the math in ways that I understood.
>
> One of Emily's rules for the film was there had to be a joke to lighten the mood of the content. As it goes with script development, it can take several iterations and constructive feedback to strengthen the story. Sometimes she didn't even have THE joke she wanted to put in, but with us students we all had our own banter and little jokes that we wanted to put in there for her.

Reflecting on their journey throughout the project, Emily and Drew highlight the pivotal role of effective communication in achieving success. Their transparent communication during the development, production, and post-production phases of the film ensured a shared understanding of their respective visions as client and animator. Further to this, Drew recommended that future animators make a good start by immersing themselves in the subject matter and says 'If your client has examples, use them at least as a starting point, as a reference. I would even argue to request a few instructional videos of what is the concept of the maths that they want to visualise. Afterall, the best way to visualise is to understand first'.

Curvature (with a squirrel)

This final case concerns the animation that explains the concept of curvature, which is the quantitative measure of how much a curve deviates from a straight line. Unlike the ideas explained throughout the Pi and tangent animations, curvature is more of an applied concept relevant to engineering students when designing roads, train tracks and rollercoasters.

As per the other animations, Emily had developed a script that featured details of the math concepts, supporting diagrams of how she taught the concepts in her lectures, and some potential jokes for the end of the film to lighten the mood (Figure 3). From this foundation, two animators presented rough storyboards where they aligned visual ideas with the content of the script. One centred on the same theme park world used in *Tangents and Derivatives, but featured the turtle-like Koopa Troopa*™ character from the Super Mario Bros™ franchise as the protagonist and cleverly tied it to 'kappa',

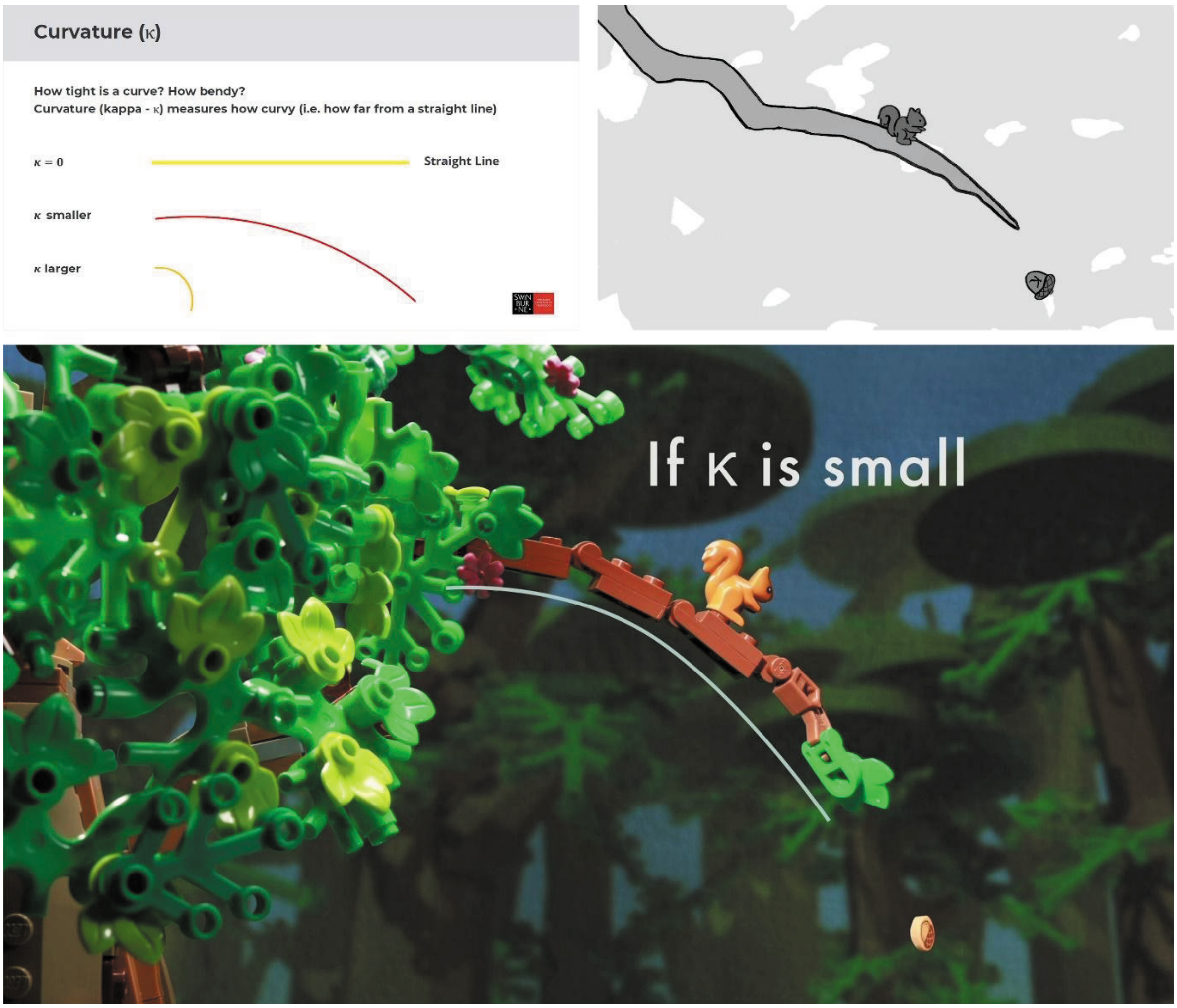


Fig. 9 The visual communication process used throughout the development of *Curvature (with a squirrel)* (2024). (Top) An initial storyboard panel from Emily's lecture slides and it's translation into an animatic by Fiona. (Bottom) A still of the same moment taken from the final animation, featuring a post-production overlay that links the typical representation of the mathematical concept to the physical and familiar scenario of a bending tree branch.

which is the Greek letter used to represent curvature. The other was set within a forest with a squirrel as the main character. Emily chose this idea, the work of Fiona, because it met all the essential criteria that had been developed for the Brick Math brand, and was set in a consistent and relatable world that presented opportunities to leverage unconventional yet interesting models of curvature. Fiona offers a useful insight into her thinking at the time.

> I think the script was fine as it was, because it was a lot of maths terms and I can't really change that as an animation student. Most of the narrative is just the visuals, because it's based on a squirrel character, but you don't really like need to hear about it. I mainly visualised it myself. Like I thought about what kind of camera shots would be good and also easy ways to maybe show the maths.

Adopting a similar approach to interdisciplinary communication as Drew, Fiona primarily communicated her creative ideas through storyboards and then via a more refined animatic as shown in Figure 9. During reviews of these artefacts, Emily would typically focus on the math components being visualised and leave the creative aspects to Fiona as the animation lead.

The maths itself for this video is at a university level, so not simple to understand or communicate. However, rather than defaulting to Emily for tutoring on the concepts, Fiona took an independent approach to develop her understanding of the math she was visualising by reading the script over and over and by watching explainers on YouTube. She explains this approach helped her arrive at some interesting and original ways to visualise the math while also adding value to the film's aesthetic, as shown in Figure 10.

> While reviewing the curvature script there was a sine-graph diagram that I found confusing. And she drew the diagram and it's like these curves, and I imagined some hills to go with it. She was really enthusiastic about it, and liked the idea.

This not only created an opportunity to visualise the math within the world, but it also enhanced the visual appeal and efficiency of the film's production by avoiding the creation and animation of multiple dense forest scenes.

Fiona's approach meant that she was able to better understand what Emily was wanting to communicate and enabled her to design sets and scenarios that visualised the math concepts while also being able to make them aesthetically and creatively pleasing. This, along with Fiona's goal to tell

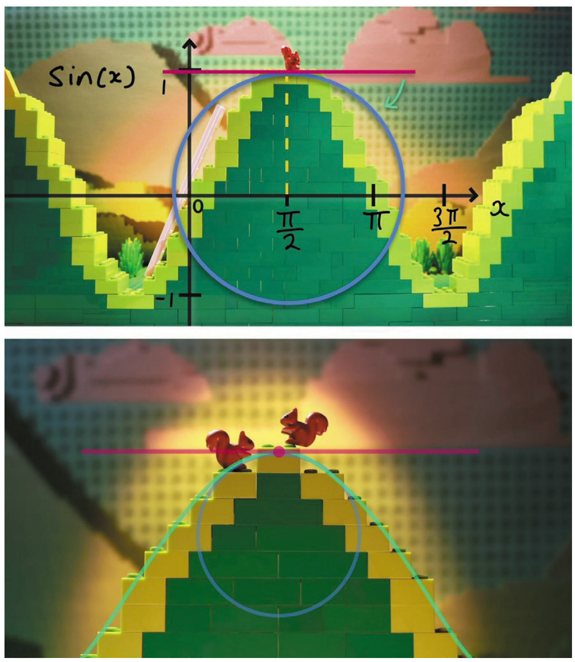


Fig. 10 Two stills taken from the film *Curvature (with a squirrel)* (2024). Both illustrate how the storytelling environment, in this case a hill, was leveraged to visualise the mathematical concepts of a sine function (top) and a curve with an osculating circle (bottom).

the squirrel's story through the forest visually, meant she was able to search for solutions within the storytelling world and only resort to the 'whiteboard' where it was absolutely necessary.

In the previous cases both animators talked about the balance between focussing on the maths and creating elaborate visuals. However, Fiona had a different take on this having commenced the project by studying Emily's earlier films on the Brick Maths YouTube channel. Her assessment was that these films had a distinctly strong and straightforward focus on explaining the math concepts, whereas the newer films being produced aimed to incorporate underlying and more orthodox narratives.

> I didn't realise we were doing all these different stories, because I watched the YouTube channel at first and it seemed like more maths focussed, but then we changed things up and added stories too… At first, I thought we were doing a lot, too much ... but then it actually turned out really nicely, so I think it's a good balance right now.

Fiona was initially apprehensive to follow suit, believing she might be doing too much by incorporating a focus on the squirrel's journey and that this could potentially divert students' attention away from the mathematics. Yet, as the project unfolded, it became evident that she, along with the other animators, managed to strike a good balance between the creative use of animation and the necessity of explaining the math concepts effectively. If Fiona were to give advice to future animators, STEM clients and collaborators alike, she recommends that all stakeholders be aware of what the overarching goal of the animation is, and be open to narrative exploration and the ideas others come up with as a way of continually improving engagement with it.

Curvature (with a squirrel) started production slightly after the other two animations, and the experience and insights Emily had gained meant that she was armed with newfound knowledge and was able to apply this throughout the development and production of this animation. Emily believes this saw her be more at ease in searching for and identifying potential issues regarding the clarity and visualisation of math concepts, and that any such concerns could be promptly identified and addressed during the film's development, production or even in post-production, the latter being a realm she had little familiarity with before engaging with the animators but was rapidly becoming aware of.

Reflecting on the animation, Emily expressed great satisfaction with the collaborative process and workflows established between Fiona and herself.

> I am exceptionally happy with this animation, especially when you consider LEGO® is an unconventional choice for teaching curves as it is fundamentally made of blocks. Early on, I had significant doubts if it could even be done, however this animation surpassed my expectations. Fiona's work is precisely the vision I had for the overall Brick Maths project. By working with her and the other animators this animation was both far more beautiful and consistent in the narrative than I had could have possibly imagined or even achieved if I were to have tackled this alone.

Discussion and Conclusion

As per the objective of this project, collaborating with animators facilitated the desired improvement of production quality and Emily's own work. The reflection process highlighted how the interdisciplinary collaboration impacted the development and production of these innovative teaching resources.

The reflections shared throughout these three cases draw attention to the critical role that clear and collaborative communication play within interdisciplinary teams, as well as the necessity to define and balance the needs and wants of all stakeholders who can have opposing goals.

Critical reflection on the processes used and the animation outcomes have led to three key insights, all of which stand to improve the authors work, and can form the objectives of future *Brick Math* research. These are: domain-specific language and communication, appreciating process and scope, and balancing creativity and technical focus.

It was interesting that the student animators found different ways of communicating with Emily as the 'non-creative' mathematics expert, leveraging visual tools such as storyboards and animatics to articulate and iterate their understanding of the math concepts and their creative intentions. Further, there was clear attempt to bridge the language gap between the two distinct domains through the adoption of physics as a common language. Examples of this included the animators moving away from their domain specific terminology such as "ease in, ease out" towards the physics domain language of "acceleration" and conversely the mathematician learning to understand animation principles such as "timing", "arcs" and "squash and stretch" as applications of Newtonian mechanics. Understanding each other's terminology and agreeing on common terms to adopt was a key feature of the interdisciplinary team working well together. The effectiveness of the different bridging languages used in facilitating interdisciplinary collaboration warrants further exploration, particularly in contexts involving STEM or other creative stakeholders who may not directly engage in the hands-on development or production of a resource.

By working with the animators, Emily learned to embrace their creative instincts and have trust in the animation techniques and parts of the animation process that she was unfamiliar with. However, not understanding processes led to challenges around the scope of the projects increasing, leading to one film being mostly complete but not finalised within the project timeframe. Had the animators not been junior-level undergraduate students and had more experience with the workflows, processes and the estimated time for each task, or had Emily had greater knowledge of all the stages needed to produce a quality outcome, they may have scaled back some of the more complex visual ideas to ensure timely completion.

It also became clear that using animation to produce educational resources necessitated a delicate equilibrium between pushing creative boundaries to produce visually captivating content and maintaining simplicity to effectively convey challenging mathematics concepts. This tension was felt in the development of detailed backgrounds and character shots to add visual interest, versus their sparing use in other shots to prioritise focus on key narrative objectives. This balance raises intriguing questions regarding the level of viewer engagement and learning associated with varying aesthetics and background details. Future work could explore how mathematics students engaging with the animations perceive the different visual elements, and which, if any, increase engagement with the content versus distracting from the key messages.

For future collaborations of this nature, the student animators recommend subject matter experts provide completed scripts while being open to creative input, and that animators possess a thorough understanding of the content through detailed reference materials and frequent communication with the subject matter expert. Lastly, they recommend to animators embarking on similar projects to prioritise the simplification of creative ideas to maintain focus on educational messaging and to alleviate time and complexity constraints.

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