Storyboard Physics

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ABSTRACT

Storyboard Physics is a narrative approach to helping students understand core concepts within the physics curriculum. Each concept is introduced in a set of short episodes that is serialised on a module webpage. At the moment, the episodes are presented in the form of a traditional dramatic script, but we believe the ideal format would be as an interactive graphic novel. The fictional characters who tell our story have different backgrounds and different approaches to tackling problems. Students, as they read the storyline, may accordingly find they are in sympathy with one approach over another but, by following the dialogue, start to appreciate concepts holistically. Our characters discuss physics in a way that springs naturally out of their working lives; their personal relationships are however a crucial part of the format, further encouraging students to follow the narrative. Although the narrative is instructor-led, it is important to have student members of the writing team. We discuss our pilot study done as part of the HESTEM Conceptual Understanding in Physics project. This approach is easily generalised to other sciences.

Keywords
Communication, education, educational philosophy, educational aids.

1. INTRODUCTION

Physics can be transmitted and grown by conversation. Even-handed participation in a small group tutorial is one way to facilitate this. However, it is economically more and more difficult to run tutorials on a scale, and with an intimacy, that encourages students to field and defend their own ideas or approaches to understanding. In addition, modern discourse is now conducted online through social networking sites and forums and this provides new opportunities for interactive learning. There is something Darwinian about social online learning – stimulating approaches flourish by generating regular visits and engagement with organic (if often unexpected) mutation. A nice example of this is the *Project Euler* website (projecteuler.net/) where ingenious solutions and solution commentary are trained on a trellis of graded and structured computational problems. The structure for *Storyboard Physics* is the meetings and conversations of three young fictional people. The challenge is to grow the storyline and develop the physical concepts in a natural and symbiotic way.

2. EPISODE STRUCTURE

An individual concept is introduced and developed over a series of episodes – we settled on about five - enough time to allow the conversation to evolve but remain fresh. We used a small focus group to proof test our format. The members of the group had very different levels of base physics knowledge and responded to the episodes in different ways. Each episode takes no more than half an hour to read as a straight narrative and has the structure of a scene in a play. The story is continuing over the series so that we use the usual dramatic devices – unresolved plot elements, cliffhangers - to maintain involvement. We also added a cryptic puzzle to each episode. First, we thought this could open up discussion on relatively neutral ground. Second, we were trying to encourage a longer look, at say a picture or a graph, than you might volunteer on a first reading when following the thread of the story or argument takes precedence. We wanted to include mathematical details but we were aware they can slow the narrative pace. So we designed ways in which they could be embedded in the story but perhaps read in detail once the episode had been digested. As examples, we had photographs of pages of the characters' notebooks, scribbled explanations on whiteboards, and extracts from their lecture notes, all bringing a sense of informality to the technical parts. The focus group found this unusual and appealing but told us to be wary of its overuse and worried if hand-written notes would be accepted as authoritative in the same sense as professionally prepared books and websites.

3. CHARACTERS AND LEARNING STYLES

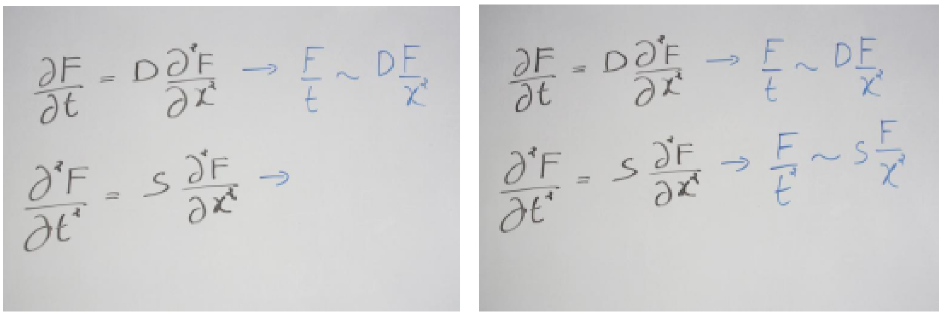
Of course, what we are describing has its natural precedent in Galileo's wonderful dialogues (Galilei rep. 1954) but no-one would describe those as even-handed! Similarly Mr Tompkins (Gamow 1949) is a wonderful read but we don't really enter the narrative in the sense of sympathizing with particular opinions or characters. More recently, Don Knuth had Alice and Bill discuss number theory, cooking fish and getting pregnant (Knuth 1974); but for all the domestic detail, Alice and Bill never seemed like natural additions to a mental house-share, people whose personal lives might bring you back repeatedly to a story. Not that all characters need be empathic; the contemporary nightmare of the physical house-share, Sheldon Cooper in "The Big Bang Theory", has become a standard referencing source of physics hearsay. So there are nice examples of narrative and science working together but none that quite match what we had in mind. Two members of the *Storyboard Physics* team were recent graduates and could bring a sense of what kind of story and story-telling style a student might enjoy following and returning to. In homage to Galileo, we chose three young Italians as our protagonists. Silvana is a computationally inclined engineer. Her first inclination when faced with a problem is direct simulation. Salvatore is a physicist with a good feel for the way in which mathematics represents phenomena. His style encourages estimation and his calculations are used to test the simulations. By contrast, our third character, Sergio is a film critic with little scientific background. He does however enjoy numerology and puzzle-solving. At times his interest in the discussions is a little disingenuous, only encouraged by the idea of spending time with Silvana, a weakness consistently exposed by Salvatore. Sergio's presence however does allow the discussion to remain grounded in everyday experience.

4. SOME EXAMPLES

We chose pipe flow for one of our early series and, in the limited space available here, will focus on this example to illustrate our general approach. Pipe flow is readily pictured, has some analytically tractable limiting cases, but can be extended through simulation to less familiar cases that act as useful tests of physical intuition. The simulations were conducted in *STAR-CCM+*, a versatile computational fluid dynamics package with attractive and readily interrogated output.

Figure 1 shows the appearance of a typical page from an episode. In this example, we follow Silvana and Salvatore as they work up a calculation to back up the results of a simulation shown in Figure 2. We found the output of *STAR-CCM+* to be visually easy to interpret, and even our less scientifically prepared focus group members found the images accessible. When there were ambiguities, Sergio would chip in and make sure the other characters clarified their meaning or interpretation (Figure 4). Figure 3 shows the opening of an episode; we use photographs as a form of virtual laboratory. In this case, our readers are invited to work out how the Michell ball and cup viscometer (illustrated in the picture) actually works. A brief video clip posted with the next episode answers the question although our projected implementation would allow for web-post discussions before this. Figure 5 shows how the script is paced by balancing glimpses of the physical and social storylines.

Salvatore	That's right. It's a great experiment for lazy people.
Silvana	Now I have to guess which equation is the diffusion equation.
Salvatore	Like I said no guess required but a nice trick. We strip off all the partial '*d*'s' like so:



Silvana	This is the kind of maths I like.
Salvatore	Now you have a go at rearranging so that *x*, the distance, is the subject of both equations.
Silvana	Ah now I think I see. The second one where *x* is proportional to time *t* is the wave equation.
Salvatore	Right.
Silvana	So the other one is the diffusion equation.

Figure 1: A sample text from one of the pipe flow episodes. Salvatore is trying to show Silvana how to calculate the entry length within the pipe – the distance it takes to establish a steady equilibrium profile.

Silvana	So I get say 2.3 cm.
Salvatore	Let's look at the simulation. In this close-up, it's pretty much reached a steady state by the right hand side.

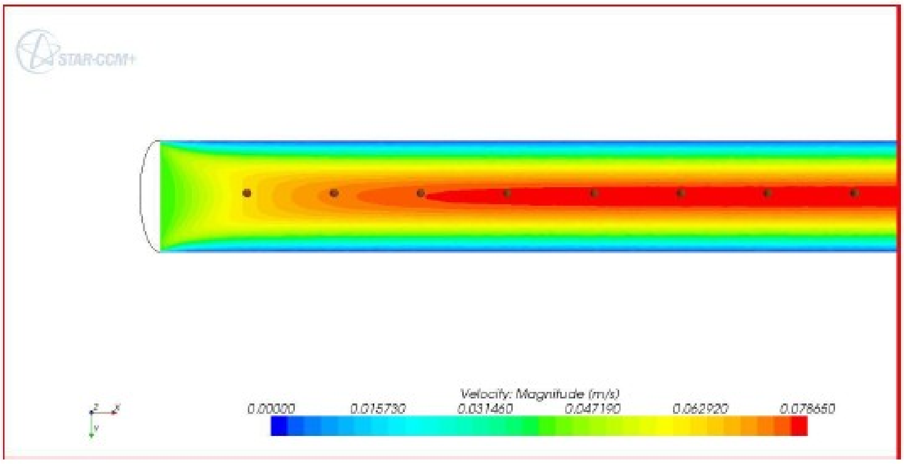


Figure 2: The outcome of Silvana's entry length simulation. The colours represent velocity magnitudes in the flow which enters the pipe on the left-hand side of the pipe. Note how the flow approaches a steady profile toward the rightmost end of the pipe.

Episode 2: In which Silvana has a birthday and receives an unexpected present

The next day at Silvana's flat. Sergio arrives and Silvana lets him in. Sergio is taken aback to see that Salvatore is already there, is unshaven, and seems to be making himself at home. Sergio is carrying a small package which he gives to Silvana.

Sergio	Happy Birthday Silvana!
Silvana	*(Sergio passes her a card and wrapped gift)* Ooh thank you..and thanks for getting me a card without my age on (*Sergio smiles with pleasure*)

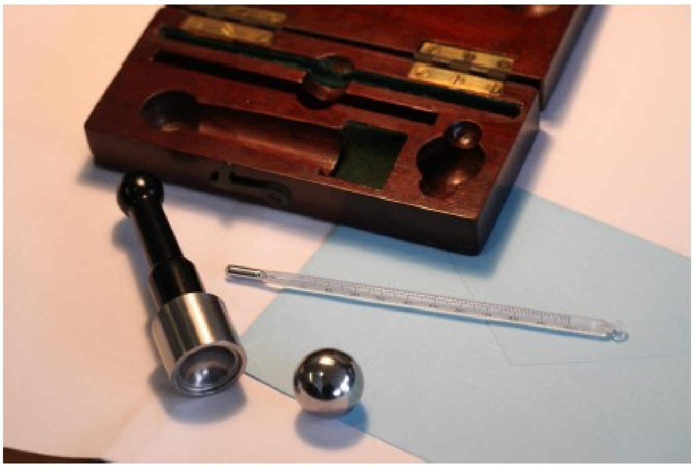


Figure 3: We made a deliberate policy of varying our images – too many false-colour simulations can soon blur one into the other and lose impact. We wanted a nice blend of direct experimentation (viewable on video clips), using relatively simple kit such as the viscometer pictured here, and mathematical and computational analysis.

Sergio	Didn't know that the blood changed its colour inside a blood vessel.
Silvana	It doesn't. It's not the actual colour of the blood. The colours indicate the blood flow speeds, red is fast and blue is zero – see the scale on the bottom?
Sergio	Why's it zero on the edge?
Silvana	Good question *(Sergio beams)* The drag on the blood at the surface slows it down so that we can effectively regard it as not moving at the wall.
Salvatore	It's called the no-slip condition.
Silvana	If you look carefully you can see that this slowed down fluid then slows down the blood flow next to it.
Sergio	I can see that. But after a while the colours don't change across the pipe.
Silvana	It reaches equilibrium. If there wasn't pressure pushing the fluid down the pipe, it would eventually all come to rest.
Sergio	The aorta isn't that long! I've seen a Discovery Channel programme about heart diseases.
Salvatore	Let me guess – you started shorter but couldn't get the equilibrium. So you made it so long it no longer fits inside a chest.
Silvana	Right and I still didn't get the parabolic velocity profile across the pipe promised by the textbook – here's

Figure 4: The focus group found conversations such as the one above useful. They could then understand mechanistically what was going on even when the mathematical details were a little advanced.

Silvana	Sorry we didn't get to that movie last night. Did you need to see it for work?
Sergio	If I watched all the films I reviewed, I wouldn't have a life.
Silvana	So you can review a film you haven't seen – how does that work?
Sergio	Here (*He passes her a sealed envelope*) – open this. The list you're looking at is next week's press screenings – I'm meant to attend them all. However, they send the title and a short description. I'll show you how it's done - give me the first title
Silvana	*Termites on a train*
Sergio	It's *Snakes on a Plane* but without snakes and the plane. My review is 'Shamelessly derivative - this is a franchise that has no legs – just like the snakes.'
Silvana	(*laughing*) But it could be really good?
Sergio	Really Silvana – how many termite movies have you enjoyed? These films weren't meant to be watched – we review it so that others don't have to see it. Next one?

Figure 5: It is very important to us that the characters are friends and have social lives in parallel with their working ones. The extract from an episode above shows that we are trying to tie people into following the development of physical concepts with a parallel storyline in which we see their personal relationships develop.

5. SUMMARY CONCLUSIONS

Storyboard Physics is in its early stages of development but we have received encouraging feedback that has led us to revise and re-evaluate our implementation. It is labour-intensive to create but it has the virtue that it can accommodate different learning styles by sensitive identification of characters. In this way, students can empathise with one approach but come to appreciate others as the interplay of learning styles threads its way through the narrative. Although our interest is in physics, it is not hard to see implementations in different fields. The titles of our episodes give some idea of the informality we tried to achieve: we kept them deliberately enigmatic so that students couldn't skip to relevant principles or equations without absorbing a discursive argument. We added levels of content e.g. embedded puzzles and illustrations that need to be studied carefully. So, on one reading an episode can be absorbed relatively quickly. The extended mathematical details and experimental references require extra thought but this needn't interrupt the flow of the first read-through. Where technical details are central to the narrative, they are broken down into manageable steps laced with dialogue. We wanted the discussions to be open to intellectual detours. For instance, as we planned the pipe problem, we wondered what would happen in a cored pipe with a coaxial solid cylindrical core. In particular, we wanted our characters to try and work out where the maximum speed was in the gap between the surface of the core and the inner surface of the pipe. Which surface was it closer to? There are reasonable arguments both ways and we had our characters not only resolve the conundrum by experiment, but also devise new tests of their resulting hypothesis. This again is the beauty of having a blend of experiment, simulation and mathematical analysis.

6. ACKNOWLEDGEMENTS

The authors are grateful to Professor Derek Raine who very kindly offered financial support from the *HESTEM Conceptual Understanding in Physics* project to help develop this pilot.

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