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Engineering Magical Learning Environments*

NATHANIEL LASRY[1,2,3] and PIERRE-OSIAS CHRISTIN[1]
[1] Physics Dept, John Abbott College, 21 275 Lakeshore Rd, Ste-Anne-de-Bellevue, QC, Canada. E-mail: lasry@johnabbott.qc.ca, pochristin@hotmail.com
[2] Center for the Study of Learning and Performance, Montreal, Canada
[3] School of Engineering & Applied Sciences, Harvard University, 9 Oxford Street, Cambridge MA, 02138, USA.
E-mail: lasry@seas.harvard.edu

Students enter science classrooms with numerous conceptions, many of which are partial and inaccurate. Misconceptions can be addressed by designing demonstrations that are counter-intuitive to students. Just as magicians use unexpected observations to entertain their audiences, demonstrations become magical when they are designed to breach student expectations in an entertaining and non-threatening way. This paper provides instructors with practical means to convert classical demonstrations into magic tricks. To illustrate the procedure, two classical demonstrations are re-presented as magic tricks that we have used in our college classrooms.

Keywords: magic; demonstrations; inquiry; conceptual change

1. Introduction

One of the major goals of education is to help students make sense of what they learn outside of class [1]. Yet, in school, learners are often faced with abstract tasks that have no clear logic or meaning to them [2]. How can we help students bridge the gap between knowledge learned in class and knowledge that has relevance and meaning to students beyond the confines of the classroom?

The focus of this paper is to presents *magic* as a method that makes concepts more relevant and meaningful to students, both inside and outside of the classroom. This paper has two simple objectives. The first is to share the excitement of designing magical classroom demonstrations. The second objective is to provide instructors with practical means of when and how to convert classical counter-intuitive demonstrations into magic tricks. Two classical demonstrations are presented as magic tricks for illustrative purposes.

1.1 Addressing misconceptions

From coin or card tricks to large stage illusions, unexpected outcomes are at the root of all things magical. Although thwarted expectations can produce audience awe and wonderment, unexpected outcomes in classrooms often cause student dismay and confusion. Students bring large bodies of knowledge with them in science classrooms. This previous knowledge is often incompatible -and may even interfere- with the concepts that are being presented to students [3]. Many misconceptions, with respect to classical physics for instance, have been identified [4–5]. Addressing these misconceptions explicitly has been shown to facilitate conceptual learning [6]. The suggestion in this paper is to design demonstrations where the students' misconceptions are used to create an expectation that is thwarted in an entertaining and non-threatening way. To facilitate conceptual change, magical demonstrations use cognitive conflict, the reaction to a situation that cannot be accounted for within a set of preconceptions [7].

The conceptual change literature suggests that the cornerstone of effective instruction is to identify and explicitly address students' misconceptions [3–6]. In magic demonstrations, instructors use misconceptions to setup an expectation that is thwarted by unexpected observations. The observations are then used as the starting point of an inquiry cycle wherein learners construct new knowledge and conceptual understanding. Focusing exclusively on the cognitive aspects of magic however is insufficient. Indeed, the mind can be seen as the interplay of cognition, affect (emotions) and conation (motivation) [8]. Hence, focusing only on cognition is incomplete.

Students will often acknowledge that magic demonstrations trigger emotions that are rarely aroused in higher education courses. From a neuro-cognitive perspective, new (declarative) knowledge is processed by the Hippocampus[9], a brain structure located within the temporal lobe. The Hippocampus is also a component of the limbic system: the mind's emotion-processing unit. Thus, new knowledge is processed by a structure also involved in processing emotions. Empirical evidence demonstrates the interplay between emotions and learning. For instance, memory is known to be enhanced by emotional stimuli and these memory gains are eliminated when the encoding or consolidation of emotions is blocked chemically [10]. We are compelled to conjecture that magic demonstra-

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tions aid learning and recall because of the enhanced emotional arousal. Magical demonstrations address the three dimensions of mind: cognition through cognitive conflict; emotions through the reactions to the tricks and motivation as the resulting desire to inquire about the functioning of the tricks.

Magic demonstrations are interesting and fun. Arguments have broken out as to whether the fun is greater for the teacher or the student. These contentious issues however remain outside the scope of this paper.

1.2 Why should teachers use magical demonstrations in class?

Demonstrations are often used in classrooms as great tools to liven up a lecture. Students seem to perk up and pay closer attention. But are classroom demonstrations effective?

In a study from the Mazur group at Harvard, students passively observing a classroom demonstration were found to learn no more than those who had not seen the demonstration at all [11]. To be effective, demonstrations must actively engage students, for instance, by asking them to predict what will happen. When the outcome differs from the prediction, a cognitive conflict may be experienced and the likelihood of learning is increased.

Magic demonstrations actively engage students by using a common misconceptions to create an unexpected observation. When the tension and drama are properly built into the trick, as will be described below, cognitive conflict is facilitated. It is also useful to have students learn these magic tricks. Although students might perform the tricks in purely social contexts outside of class, hands-on experience with these demonstrations is likely to contribute to conceptual change.

1.3 When should a magic demonstration be presented?

Demonstrations are often setup as validations of a concept or principle presented in class. As such, they can reinforce the perception that 'the instructor is always right'. Our magic proposal has three parts. The first part involves rethinking demonstrations to avoid presenting them as validations of a concept. The second part consists of identifying one or more misconceptions that are commonly held. Finally, a demonstration is designed to violate students' intuitive expectations in an entertaining and non-threatening way. Students holding the misconception are then confronted with the unexpected outcome. The instructor can then use the unexpected observation as a entry point for enquiring about the phenomenon demonstrated.

2. How to make a demo magical

Two demonstrations are presented below. The most classical demonstration, the bed of nails, will be presented first, followed by the double conic roller (center of mass demonstration). Although, these demonstrations may be familiar to seasoned teachers, the purpose here is to show how familiar demonstrations can be made magical.

2.1 The bed of nails

Traditionally, this demonstration is used to illustrate the concept of pressure as the ratio of force over surface area. A formal presentation of the concept of Pressure is usually followed by the demonstration which 'confirms' the concept. Our first suggestion is to reverse this sequence.

The instructor performs the bed of nail magic trick by suggesting that s/he discovered the path to occult powers. A turban is placed on the instructor's head to tune into the students' mental 'vibes'. This tuning should allow levitation to occur. A brief meditation moment is taken. The instructor, displaying much hesitation, states his/her apprehension of doing this magical feat and decides to take a bite out of an apple to relax. The apple is clumsily dropped onto the bed of nails and retrieved perforated, showing the sharpness of the nails. The dropped apple makes explicit the preconception that anything in contact with the nails will be perforated. Students are then asked to focus their 'mental energies' and 'send positive vibes'. While chanting a mantra, the instructor, encouraged by the students, resolves (not without hesitation) to lie down on the bed. Students expecting the worse (or best, depending on the student and the outcome . . .) observe the instructor lying down onto the bed of nails. They are then asked to explain why the instructor was not transformed into a sifter and the inquiry cycle begins.

There is an interesting complement to this demonstration. Once the concept of pressure seems to have been properly understood, students may be asked to predict whether the instructor could walk on the bed of nails without shoes. The instructor positively acknowledges responses contradicting the possibility of walking on nails and proceeds to explain that it would indeed be impossible. The instructors' weight could not possibly rest on such a small surface as a foot without being perforated (at least not with this surface density of nails). During this explanation, the instructor removes his/her shoes (but not the socks) and proceeds to walk on the bed of nails! While walking on the nails the instructor continues to emphasize the impossibility of this feat at every step. When students ask why it is that the instructor is able to walk on the nails, the instructor steps down from the bed of nails, removes the socks and reveals 2 cardboard insoles hidden inside the socks! The instructor suggests that critical thinking requires one to go beyond appearances.

2.1.1 Deconstructing the demo

This demonstration is an ideal magic demonstration since it is traditionally performed by magicians and fakirs. The effectiveness of the demonstration lies in the preconception that anything in contact with nails will be perforated. Dropping the apple contributes to making that expectation even more explicit. Furthermore, hesitation towards performing the trick also adds to the tension as a number of students may urge the instructor not to proceed (or to go ahead, depending on the student . . .). Thus, the primary aim is to trigger a cognitive conflict with the preconception and allow students to conceptualize pressure as the ratio of force over a surface area.

Once the students seem to have understood the concept, the instructor can then present them with the second part, an application of the concept to a slightly different context: can one walk on the nails (i.e. same weight but much smaller surface area)? Once again, this portion is set up to maximize cognitive conflict as the students having acknowledged that the pressure is inversely proportional to the surface area are conscious of the difficulty of walking on a bed of nails. The conflict is maximized when the discourse of the instructor is in direct conflict with the students' observation; until the cardboard insoles are revealed and the impossibility of walking on nails is confirmed.

2.2 The double co~~m~~nic roller

Among great 'center of mass' demonstrations, available from most lab equipment providers, is the double conical roller placed on an *inclined wedge*.

If one places a pen on the elevated side of the wedge, it will roll down the incline towards the narrower part of the wedge. However, when the double cone is placed on the 'bottom' of the incline, it will roll 'up' the incline. Indeed, the center of mass of the double cone is propped up where the wedge is narrower although this happens to be the 'bottom' of the incline. The roller sinks into the wedge as it gets wider towards the 'top' of the incline. This gives the impression that the double-cone rolls up the incline when in fact it is rolling down into the wedge. So the pen seems to move down the incline while the double cone seems to move up the incline. Usually, this demonstration is presented and center of mass dynamics are discussed.

To present this demo as a magic trick, one shows the inclined wedge and wood double cone. It is useful to hand these out to 1 or 2 students for inspection so they can make sure that there are no 'gimmicks' (students usually look for magnets). The instructor then shows that one part of the incline is elevated by letting a pen roll down the incline.

With a deep breath and tremendous concentration, the instructor states that, with the mind's power, telekinesis will be performed, and the double cone will be . . . dragged UP the incline, 'against' gravity (drum roll . . .). The double cone is then released from the bottom of the incline and rolls towards the top of the incline. This portion constitutes the unexpected, the '*here's what actually happens*' part of the demonstration.

As the double cone proceeds up the incline, the instructor's hands precede it and seem to be magically pulling it upwards. When the double cone reaches the top, the instructor quickly picks up the double cone (since the 'trick' would be spoiled if the cone just sat there for a lengthy period of time). A long sigh is released indicating the tremendous mental effort that was required.

Usually, students will ask this trick to be performed again. It is useful to repeat the trick once or twice. Students can focus on different aspects of what they believe is happening. Students usually volunteer explanations and discuss collectively. The instructor can then ask the class to 'debunk' the trick to and a guided inquiry process begins.

2.2.1 Deconstructing the demo

The first part of this trick consists of making the preconception explicit: the '*here's what you expect*'

Fig. 1. The left side of the wedge above is elevated. The pen rolls 'down' along the edge towards the right. The double cone on the opposite end has an elevated center of mass when it rests on the narrower end (right side) of the wedge. When released, the double cone rolls left and 'sinks in' the wedge as it widens. This demo shows the pen 'falling to the right' while the cone 'falls to the left' which gives the illusion that the double cone is going up the incline.

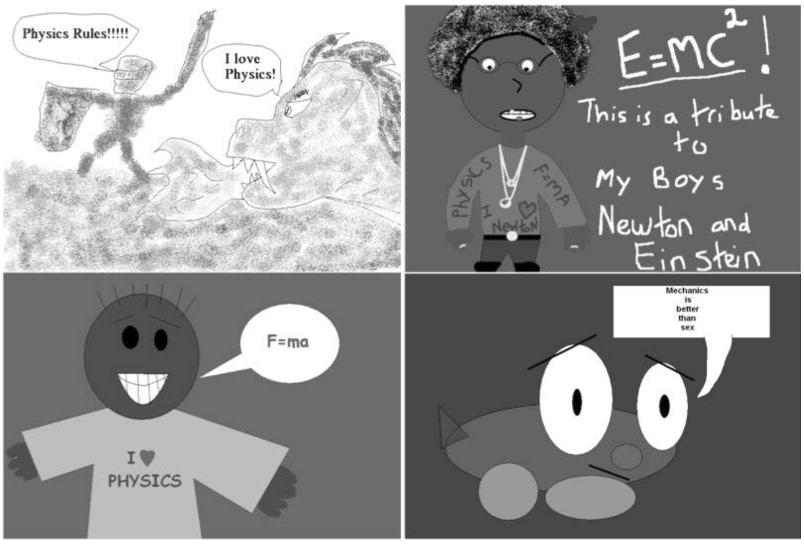

Fig. 2. Unsolicited student feedback in the form of screen savers created by students on laboratory computers in an inquiry physics course that made use of magical demonstrations.

portion of the demo. The importance of this part cannot be overemphasised. Without a clear expectation, a strong cognitive conflict cannot arise. In this demonstration, the pen is rolled down the incline to show that one side is 'higher' than the other. Because both objects have centers of masses that will move along different paths and that *'what constitutes 'high' and 'low' is relative: if it is High for one object it may not be High for all objects'*. Thus, two objects on an identical support may have different 'highs' and 'lows' and may therefore fall in different directions. This observation should trigger cognitive conflict and facilitate the ignition of a guided inquiry process.

3. Student feedback

Attending a college course where magic is part of the classroom culture has a visible impact on students attitudes towards science. After using magical demonstrations in mainstream physics courses, one of the authors (POC) compiled a vast number of magical demonstrations and designed an entire course for non-science majors on the physics of magic. Registration in this course over the past decade has always been at maximal capacity (registration being limited by the seats available in the laboratory) and students are routinely turned down at registration because the class is full. Besides the informal feedback the authors frequently received over the years, we can objectively state that non-science majors enjoy and highly recommend this approach because they continue to register for this course in record numbers.

Science majors also appreciate magical demonstrations. In a mainstream introductory physics course, one of the authors (NL) gave magical demonstrations routinely as a complement to other inquiry based approaches. Though all computer screens had a similar background when the students came into the laboratory, at the end of class some computer screens were found with MS Paint screen-savers. Four student-created screen-savers that addressed physics are displayed below.

Although the authors do not endorse all messages contained in these student screen-savers, we do feel confident claiming that magic changes the learning landscapes and creates an engaging and positive learning environment.

4. Conclusions

Presenting demonstrations as magic tricks allows instructors to challenge student misconceptions in an entertaining and non-threatening way. The process of turning a demonstration into a magic trick can be applied to a large number of demos. The main requirement is that a misconception can be made explicit and that a demonstration can be designed to yield an unexpected observation. Demonstrations can also involve deception to make the observation even more unexpected. For instance, we have modified the classical Bernoulli's principle demo where a ping-pong ball floats above a blow dryer by hiding the blow dryer below a table. With magic ambiance music sufficiently loud to cover the blow dryer's noise, the instructor can then release a ping pong ball in the air and make it levitate. Class time can then be devoted to 'debunking' the trick and an inquiry process can be initiated.

From a cognitive perspective, creating such unexpected situations sets the stage for the cognitive conflict which should facilitate conceptual change. That is, the cognitive conflict should cause students to reassess their existing model and eventually change their conception to accommodate for the unexplained observation. However good this cognitive argument, you may be inclined to respond to the affective argument (that also provided the impetus for writing this paper): using magic demos in class is simply too much fun!

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Nathaniel Lasry is professor of physics at John Abbott College, a faculty member of the Center for Study on Learning and Performance, an Associate at the School of Engineering & Applied Sciences at Harvard University and the founding president of the Quebec Association of Physics Teachers. He currently splits his time between teaching physics and doing research in science education. He is also the author of *Understanding Authentic Learning: from social practice to neuro-cognitive processes* and of several papers on science education, ranging from neuro-cognitive models of learning to the effectiveness of technology in classrooms. Nathaniel Lasry is the 2010 laureate of the Canadian Association of Physicists' Teaching award. Dr Lasry is also passionate about teaching science through magic, something he can be seen doing on his YouTube Channel (www.youtube.com/nlasry) and occasionally on the Discovery Canada channel.

Pierre-Osias Christin is a retired professor of physics at John Abbott College. In a teaching career that has spanned over more than 40 years in locations as remote as south-eastern Africa, Pierre has taught science to a variety of students from high school to university levels. Pierre has frequently been involved in administrative tasks, such as designing professional programs and implementing new courses, such as the Physics of Magic course for non-science majors. Pierre was the 2007-2008 John Abbott College teaching award laureate and John Abbott nominee for the that year's Association of Canadian Community Colleges Award of Excellence.