ANALYZING THE ROLE OF DIGITAL MEDIA IN SCIENCE EDUCATION: A DISTRIBUTED COGNITION APPROACH

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Science education is a difficult cognitive process because (1) the dynamic phenomena science studies are often not available to human perception and (2) students are required to imagine dynamic phenomena in detail using dense, opaque static representations developed over many iterations and revisions in science practice. In the traditional classroom, the teacher attempts to animate the static representations to aid students' imagination. The advent of digital media, with its potential for dynamic representations, provides new ways of solving this problem, heralding systemic changes in science education that are difficult to analyse and predict. We use a distributed cognition framework to analyse a case study of a private school in Mumbai, examining how cognition is distributed across teachers, learners and representations in a static media classroom, and how this distributed structure of cognition is changed by one form of digital media.

INTRODUCTION: THE PROBLEM OF SCIENCE EDUCATION

Learning science is a goal across educational systems around the world, with few exceptions. Yet science education is a difficult cognitive process for several reasons. To begin with, many of the phenomena that science studies are not directly available to human perception, such as the reactions between molecules or the movements of planets. The way these phenomena are captured is through mental models and external representations of those models, developed over several iterations and revisions within science practice. The final models and their representations are often dense and opaque products, containing no trace of the long process of their development.

In addition, because our primary media for storing and sharing knowledge in the past few centuries have been text-based, the external representations, at least till a few decades ago, have been constrained to static representations of dynamic phenomena. A significant, and difficult, problem in science education is thus to help students understand, and imagine, the relationship between these dense, opaque static representations and the dynamic phenomena they represent, and to help them develop detailed mental models of the unperceivable entities and systems that science often studies.

As an example of this, consider a chemical reaction. The reaction is a dynamic process occurring at a molecular level that is impossible to perceive. Instead, most students learn about chemical reactions by looking at chemical equations and graphs, both of which are static representations of the dynamic phenomena of the reaction. At best, learners may have the chance to enact the same reaction in a laboratory and observe changes in some macro level properties. Students are then expected to combine these multiple external representations in their minds to create a mental model that captures the dynamic reaction taking place. The ability to do so is termed representational competence and is a highly valued goal in science education (Pande & Chandrasekharan, 2014).

So far, the way to develop these mental models in learners has been through teachers in the classroom. The teacher would aid students' understanding and imagination by trying to animate the static representations through whatever means may be available, for example a classroom board or their own voice. However, the advent of digital media, with its potential for dynamic representations, is providing new ways of addressing this conversion problem. These dynamic representations can capture the dynamic phenomena of interest in a more accurate manner, reducing the burden of imagination on the learner.

Dynamic representations can expand the education system's scope radically, in ways comparable to the way the invention of written word and the printing press changed the oral learning traditions. Given the systemic nature of this ongoing shift, it is difficult to analyse the different roles digital media can/would play in the education system, and how to conceptualize, design and incorporate such media into this complex system, to bring about desired changes. In this paper, we seek to develop a theoretical framework that can enable such a system-level analysis.

THE DISTRIBUTED COGNITION FRAMEWORK

The distributed cognition framework was used by Hutchins (1995) to describe how an aeroplane cockpit with pilots and instruments that acted as cognitive artifacts was able to perform complex cognitive tasks, like landing, in a manner that was inexplicable by just talking about cognition at the individual level. Hutchins demonstrated this by detailing how the pilots used speed bugs to reduce their cognitive load while landing. Each aircraft model has a table of permissible speed ranges that the aircraft should stay within at different stages of descent and landing. These ranges vary by the actual load on the flight, and hence had to be looked up using a series of charts kept in the cockpit.

Hutchins describes how the co-pilot would perform this lookup and set the plastic bugs on the speed meter to indicate the relevant ranges for each stage. This allowed the pilot to simply perform a single lookup on the speedometer to ensure that the aircraft was flying within the permissible range. This in turn allowed the pilot to focus on the many other procedures that a complex task like landing requires. Hutchins' contention was that the cognition occurring during this process could only be described by considering a distributed cognition system between the pilots, the charts and the speed bugs that allowed for a rather different quality of cognition than would be achievable by individuals alone.

More recently, the distributed cognition model has been extended by Chandrasekharan and Nersessian (2014) to show how such a distributed system can tackle not just well-defined tasks like landing an aircraft, but even open-ended tasks such as scientific discovery. Through a case study of a bioengineering lab, they show how computer models can be used by scientists working in a lab to extend their cognitive powers. Specifically, by playing around with the model, the ability of the lab as a whole to imagine and simulate different scenarios increases in a manner that cannot be attributed any individual's cognition alone. Instead, the scientists and the model couple together to form a distributed cognition system that allows them to perform tasks of a complexity beyond what they could achieve on their own.

In this paper, we seek to extend this model to the process of education, particularly to science education. From a civilizational standpoint, scientific discovery is a collective, distributed process that can take place over distinct instances in time and space. One of the primary purposes of science education in this regard is to transmit the accumulated scientific knowledge of human civilization to learners so they can benefit from as well as contribute to that body of knowledge. The primary cognitive artifacts that enable this distribution are the media of transmission, and the question that arises is how the nature of the distributed cognitive task of scientific learning changes with the change in the potential of these media. Specifically, how can the potential of digital media to transmit dynamic representations of dynamic scientific phenomena enhance the distribution of scientific knowledge?

We begin by looking at a specific case of how digital media was used to flip the classroom in a private school in Mumbai. We examine how this pedagogical method of the flipped classroom changes the nature of distributed cognition in science education in the school, and then broader implications of these kinds of changes for the education system in general.

THE FLIPPED CLASSROOM AT R. N. PODAR SCHOOL

The flipped classroom is a method of instruction that aims to exploit the capabilities of digital media by allowing students to watch videos of lectures at home, while classroom time is used for problem-solving, project-based activities or other learning tasks that build on and reinforce the concepts introduced in the lecture. There is some debate as to the exact definition of a flipped classroom. In a survey of the literature Bishop and Verleger (2013) define it as a pedagogical method wherein technology is used to automate aspects of instruction that can be automated. This in turn should free up classroom time for collaborative and active learning, which cannot be automated. For our purposes, this definition should be quite suitable.

R. N. Podar School, a private school in Mumbai, has been using this flipped classroom methodology to teach science for the last two to three years. The school first started off using the flipped classroom method when some teachers were short on time available to finish the science curriculum for eighth grade students. With the final exams approaching, they turned to Khan Academy videos, which they sent to their students to watch before class so they could save time on lecturing. Because of the positive response to the measure from students as well as teachers, the school decided to implement this methodology across middle and high school, starting with the math and science disciplines. Eventually, to be better able to tailor the videos for their needs, the school decided to record its own video lectures. This brought the added advantage of having faces familiar to the students in the videos.

The implementation is still a work in progress, with videos for more topics being continually recorded so that the respective classroom sessions can be flipped. There also seems to be a learning curve associated with this new method. The role teachers play while recording or during class is not one they would be used to in a traditional lecture, and they have to plan and prepare afresh for these sessions. Students, too, have to undergo a paradigm shift and take more ownership of their learning by ensuring they watch the video before class. Some methods of enforcement, such as questions that have to be answered before class based on the videos, are being experimented with in this regard.

While the response to the initiative has been generally positive, there have been some drawbacks pointed out, especially by the students. These revolve around the recorded lectures not being engaging enough, or students not being able to clarify doubts arising from the videos. Video engagement should improve as teachers become more experienced at the recording process. The absence of a teacher during the recorded lectures, on the other hand, is an inevitable consequence of flipping the classroom, but can be partly mitigated by classroom groups on social media networks, where questions can be asked and answered. Currently these consist of WhatsApp groups and Facebook pages dedicated to each section, but other interfaces are also being explored.

The expectation from the flipped classroom is that the disadvantage of not having a teacher present during the recorded lecture should be more than offset by the benefits of the pedagogy. Part of the benefits accrue from having recorded lectures readily available for the students to re-watch and revise as necessary. However, the major positive feature of the flipped classroom is that it frees up classroom time for various learning activities and enhanced interaction. By shifting the basic exposition to the subject matter from the classroom to the home, it allows for other processes of learning, such as refutation of students' misconceptions, group projects, or exploration of higher-order questions, to take place in the class. Below are examples given by two teachers of the ways in which they use classroom time since their classrooms were flipped (summarized from interview notes):

Math Teacher: We generally make groups and conduct pair-and-share activities or games. The idea is to encourage collaboration within and competition among the groups. For rational numbers, we used a maze activity in which clues had to be solved to continue in the maze. For volumes, we divided various shapes among groups of 4 students and each group presented the volume of their shape using different methods such as models, questions, presentation, blog, etc.

Physics Teacher: We have both individual and group activities – sometimes we let the students choose whether they want to be in a group or not so they can learn in the way preferable to them. Generally these activities run over 3-7 days. In some group-wise activity, one group's task is to prove the other group wrong. Once, we asked the groups to find a seventh case for ray diagrams in lens – it can't be done, but in searching for that seventh case they learnt more than they had from the previous six cases.

DISTRIBUTED COGNITION IN THE FLIPPED CLASSROOMS

A Taxonomy of Relevant Classrooms

Before we begin analyzing the changes in distributed cognition that take place in a flipped classroom, it is important to reflect on what other kind of classroom(s) we will use as a basis for comparison. The obvious one that comes to mind is the traditional lecture-based classroom. However, the flipped classroom actually differs from such a classroom on two dimensions: (1) it focuses on the use of digital as opposed to textual media and (2) the basic exposition of knowledge takes place at home before the class rather than during class.

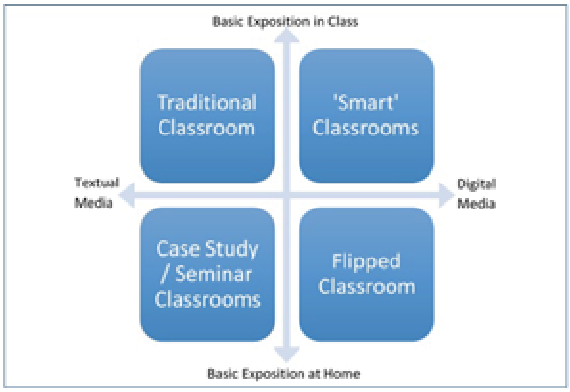

Figure 1: A two-dimensional taxonomy of classrooms

If we create a matrix based on these two dimensions, we actually get four broad categories of classrooms that are common in educational institutions (Figure 1). Of course, these are analytical categories, and empirical classrooms need not fall strictly into one of them. Nevertheless, they will provide a useful taxonomy from which to begin our analysis based on the distributed cognition framework. We briefly describe the four types of classrooms before proceeding:

1. *Lecture-based classrooms:* These, as mentioned, are the traditional classrooms wherein the teacher lectures, using little more than the textbook and a blackboard and perhaps some material paraphernalia, while the students mostly observe and take notes. The teacher is the sole knowledge-holder and the students are receivers.
2. *Case study / seminar based classrooms:* Students arrive to these classrooms having read (primarily) textual material in preparation for a class discussion and/or activity. Faculty act mostly as facilitators with some subject matter expertise, but are usually not sole knowledge-holders. This is common practice in certain higher education institutes, case studies for example in law and business schools, and seminar formats for example in certain post-graduate courses.
3. *'Smart'-classes:* A fashionable trend in the education industry, these are classrooms equipped with digital equipment so that teachers can use digital media in the classroom. Apart from the media, other facets remain similar to the lecture-based classroom. Also, the classroom media is not readily available outside the classroom.
4. *Flipped classroom:* As mentioned, here the students are exposed to the material through digital media at home, and build on that knowledge in class through discussions and/or activities. Faculty may occasionally choose to present fresh, more advanced content but primarily the focus is on student involvement in the classroom.

A Distributed Cognition Analysis

To explore the key changes in distributed cognition brought about by the flipped classroom, we need to first identify the components of distributed cognition. Hutchins (2000) identifies three key components:

> "…at least three interesting kinds of distribution of cognitive process become apparent: cognitive processes may be distributed across the members of a social group, cognitive processes may be distributed in the sense that the operation of the cognitive system involves coordination between internal and external (material or environmental) structure, and processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events" (pp. 1-2).

Within a high school science classroom, since we are primarily interested in how the quality of distributed cognition leads to better learning by individual students. The components of distributed cognition of primary interest can hence be identified as follows:

I. The interaction between learners and the knowledge media

II. The interaction between teacher and learners, as well as among learners

Each of these interactions can be affected by earlier events, and indeed the order of events is one characteristic that distinguishes the flipped and lecture-based classrooms. Also, each of these can take place inside or outside the classroom, but for purposes of simplicity we will ignore interactions made possible by social media for now (the use of social media will impact all classroom types, though in dissimilar ways – but we will not get into that here). We now are ready to examine how each of the above components is affected by the flipped classroom.

Interaction between learners and knowledge media

This component is primarily affected by the axis representing the type of media being used. We have already discussed how digital media allows for the use of dynamic representations of the dynamic scientific phenomena being studied. These dynamic representations reduce the burden of translation and imagination on the learner, and potentially reduce the amount of scaffolding required by the instructor during the initial exposition of content, as compared to the traditional classroom restricted to textual media. However, there is an important difference between the way digital media is used in 'smart' classes and the flipped classroom: in the former it is mostly used by the teacher, and with students having little or no control, while in the latter, because it is used mostly at home, students can both pace its use according to their needs as well as use more interactive forms of digital media.

Another advantage of the flipped classroom is that the recorded lectures are readily available for review at any time to the learners. Thus these videos act as an aid to the learner's memory. In the other types of classroom, the learner would have to rely on textbooks and notes to review what had been taught in class, but these are again static representations of a dynamic lecture. In addition, if the working memory or attention of a student was stretched at any particular point in the classroom lecture, they risked losing out on important basic content that may or may not be dynamically reproducible. With the recorded lectures, however, learners can rewind and re-watch a video as many times as needed, thus allowing them to choose the load on their working memory.

Interaction between teacher and learner, and among learners

The distributed cognition in the flipped classroom can be seen to be enhanced simply because of the interaction between teacher and learner that is made possible both inside and outside the classroom. In the other types of classroom, such interactions were mostly limited to particular stretches of time and space. With the flipped classroom, these constraints are lifted as through videos, such interactions are now possible outside the classroom as well. The quality of interactions is necessarily one-way, since ignoring social media connections, only the teacher can communicate with the students, but even in lecture-based and 'smart' classes, students possess little subject knowledge and hence can contribute only to a limited extent in classroom discussions.

On the other hand, the one-way communication outside the classroom when flipped allows for a much more robust two-way interaction between teachers and students during actual class time. As one teacher put it, "We get more time for interaction. Earlier we were pushed to finish the syllabus, but now we can provide individual attention as needed." Teachers also report more and better questions being asked in class, with one commenting on how "as part of this process, we learnt more and taught less: for some questions, we had to get back to the students."

The greater interaction and participation by students also helps informal assessments, as per teachers. In fact, one of the stages in the four-stage flipped classroom model that R.N. Podar School tries to follow is refutation, where student misconceptions are drawn out in class and addressed. While not impossible in traditional classrooms, the quality of this activity is reported to be richer in the new method.

The quality of collaboration between learners can also be seen to improve. Because students now come to class with some sense of what the new topic is about, a greater range of activities and interactions are enabled, as should be evident from the examples of activities cited in the previous section. Also, more time is reportedly available for collaborative activities among students. All of these allow for enhancements in the potential for distributed cognition within the classroom.

IMPLICATIONS FOR SCIENCE EDUCATION

The printing press revolutionized education by extending human civilization's ability to distribute ideas and discoveries to the masses at a pace impossible with the earlier oral learning traditions and the few hand-made copies of written texts. All that one need acquire was the ability to read, and a whole world of knowledge would open up. Of course, the training to read still needed to be attained, and illiteracy in many countries still isolates portions of the population from this knowledge. Written texts also constrains the media for sharing and storing information to static representations, and hence constrains the quality of distributed cognition.

Digital media holds the potential to change education systems at a scale comparable to the printing press, by lifting both the above constraints. The flipped classroom is one example of how this potential can be exploited to extend the scope of distributed cognition within the scope of a traditional schooling structure. Other initiatives, such as MOOCs, have tried to free education from institutional bindings altogether (although the success and scope of MOOCs remains debatable). Other dynamic media to change the education system are being developed at a fast pace, including video games, simulations based on body-based controllers, laboratory work coupled to simulations, graspable mathematical notations etc. The effect of these dynamic representations in the classroom, and how these would change the education system, is currently very difficult to analyse and predict. The distributed cognition framework which we have sketched provides a starting point to develop this analysis.

One potential is for a greater distribution of learning outside institutions, and according to Bishop and Verleger (2013), this possibility has raised questions about traditional college education and the value the education provides, given the high cost of tuition and attendance. Their contention is that traditional institutions should respond to this threat by increasing the value of the classroom experience beyond what a lecture can deliver, by using in-class time for collaborative and activity-based learning that cannot be automated. The flipped classroom provides one way to do this. Similar changes in practice may follow with other dynamic representations as well.

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