INNOVATIVE TEACHING WITH TECHNOLOGY IN THE LIGHT OF THE THEORY OF DISTRIBUTED CONGNITION

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This paper addresses ‘Technological Pedagogical And Content Knowledge’ (TPACK) the specialized knowledge that teachers must acquire in order to use technology in their instructions innovatively. The impact of technology on the students learning process is then discussed based on the theory of distributed cognition. Examples to illustrate the application of technological pedagogical and content knowledge with the use of the graphing calculator and dynamic geometry software to create innovative instruction are also provided in the paper.

Introduction

'Inovation' is the buzzword of our times (Lessem & Schieffer, 2010). Innovation is defined by Gallo (2011) author of the book, The innovation Secrets of STEVE JOBS as “a new way of doing things that results in positive changes”. Translated to the pedagogical arena, this implies new ways of teaching that results in positive changes in the learning process and leaning outcome of the students.

Today the enhancement in educational technology provides every teacher a powerful means to approach old content in a new way that can result in positive pedagogical changes. However, technology on its own is not capable of delivering innovative lessons that can result in positive changes in students' learning. Technology itself does and will not impact students' learning. The power of technology lies in the intersection of technology, pedagogy and content (Greenhow, 2009) - the power of technology lies in the teacher. As Shulman (1986) stated teachers have specialized knowledge that sets them apart from other professions. Shulman explained that a brilliant mathematician would not necessarily make an excellent teacher. He argued that an excellent teacher has special knowledge which lies at the intersection of content and pedagogy and hence he called this special knowledge Pedagogical Content Knowledge.

Similarly, Mishra and Koehler (2009) claimed that quality teaching is not a process of copying a few instructional techniques. Instead it emerges from deep thinking of the teacher in conjunction with the discipline that has to be taught making content intellectually accessible to the students. Integrating technology adds a new knowledge and hence Shulman’s framework has been updated and the special knowledge when using technology is called ‘Technological Pedagogical And Content Knowledge (TPACK)’ (see framework in Figure 1) (Mishra & Koehler, 2009).

Figure 1: TPACK Framework

Today mathematics teachers can be innovative teachers by using computer technology (referred in this paper as technology). However, the impact of their innovative mathematics lesson with the use of technology in the teaching and learning sessions will depend on their Technological Pedagogical and Content Knowledge.

Many researches in the past have shown that the use of technology has had positive effects on students learning (Obara, 2010; Herman & Laumakis, 2009; Nemirovsky, 1994; Ainley, 1994; Thornton & Sokoloff, 1990; Mokros & Tinker, 1987;
Distributed Cognition and the use of Technology

The theory of distributed cognition was developed by Ed Hutchins and his colleagues at University California, San Diego in the mid to late 80s (Rogers & Scaife, 1997). This theory claims that cognition is better understood as a distributed phenomenon, in contrast to the traditional view of cognition as a localised phenomenon that is best explained in terms of information processing at the level of the individual.

Salomon, Perkins and Globerson (1992) adopting this phenomenon summarised cognitive effects when using technology as "effects with technology obtained during intellectual partnership with it, and effect of it in terms of the transferable cognitive residue that this partnership leaves behind in the form of better mastery of skills and strategies."

To explain distributed cognition as “effects with technology”, I turn to Döfler’s (1993) view of cognitive processes (which also adopts Hutchins’ view of cognition). Döfler (1993) suggested that cognitive processes be viewed as a system made up of the individual, the whole context and the multiple relationships between them. Thus, the cognitive system has the subject (the individual) and the available cognitive tools which would aid the thinking process. Cognitive tools can be paper and pencil, calculators, computers, graphing calculators, television, etc. Döfler (1993) compared the thinking process to doing physical work stating that ‘There is no such thing as “pure” work without using any tool’. To attain the specific goals, one has to use tools in an appropriate organized manner. To illustrate the thinking process as a system, Döfler (1993) used the artist as an analogy. Döfler stated:

The skill and the intelligence of an artist like a painter are more appropriately viewed as being realized by the whole system consisting of the human individual and all his tools. These tools do not just express ideas and imaginations pre-existing in the mind of the artist and independently of the tools. Rather, the system of painter, brush, colours, canvas, etc. realizes the painting (Döfler,1993, p. 173)

The thinking process can be explained in terms of ‘distributed cognition’. Distributed cognition refers to the earlier described ‘system’ – the individual and the available tools where cognition is viewed as distributed over them (Döfler, 1993). According to this view of thinking, to solve a given mathematical problem, the individual can employ the available tool and his or her own mind to solve it.

To explain distributed cognition in mathematics, let us take for example the drawing of a straight line of a specific length, for example 5 cm in length. Using a ruler one can produce the 5 cm straight line. The individual need not have the skill of drawing a straight line unaided (that is free hand), nor does the individual need a mental representation of 5 cm. If the use of a ruler is not permitted, then fewer people will be able to draw a 5 cm straight line if they lack either the skill to draw a straight line or the appropriate mental representation of a length of 5 cm. With the use of a ruler, cognition is distributed in the process for producing a 5 cm straight line – the mental representation of 5 cm and the skill to produce a line which is straight are taken over by the ruler and the individual has to have knowledge about how to use a ruler to produce the 5 cm straight line.

To explain the “effects of technology”, I turn to Pea’s (1985) view that ‘intelligent’ technology “offloads” part of the cognitive process as a result of distribution of cognition, allowing the user to focus cognitive resources elsewhere. Pea claims that over time the user will develop cognitive skills to accomplish many of the cognitive processes demonstrated when using technology and would be capable of demonstrating these skills without any longer requiring the aid of the technology.

Let us refer to identifying acute, obtuse and right angles based on the respective definition of each type of angle. Using a protractor enables an individual to measure a given angle between two lines and identify the category of the angle. Since the protractor provides the measure of the angle - ‘intelligent’ technology “offloading” part of the cognitive process as a result of distribution of cognition, the user is allowed to focus cognitive resources elsewhere - the individual can observe the appearance of the various angles. Later the individual would be capable of recognizing the different types of angles without any longer requiring the aid of the protractor because he/she has developed the cognitive skill to identify the category of the angle.

Similarly using technology to draw graphs or geometric objects or perform other mathematical tasks affords students more time to focus on the actual objective of the learning session. This then would enable students to expend their cognitive processes to develop the desired skills and concepts of the lesson.

Let us examine some examples of how the distribution of cognition using appropriate TPACK enabled me to create innovative mathematics lessons which transformed the content in a way that made it intellectually accessible to the students and enabled them to acquire the desired skills and concepts.

Teaching and Learning Mathematics with Technology

This section describes specific teaching and learning activities which have been used and proved to be successful, to illustrate how the distribution of cognition with the application of Technological Pedagogical and Content Knowledge provided to create innovative lessons.

Using the TI-84 Plus Graphing Calculator to Develop Students’ Understanding of Scales

In the Malaysian mathematics curriculum, ‘graphs of functions’, is a topic learnt in the secondary level (students aged 16-17). Graphs however are drawn on paper and the scales to construct graphs illustrating the covariance of two variables are often
given and students mechanically use the given scales and complete the construction of the graphs. To change scales and redraw a graph is time consuming and hence how a scale should be adjusted to fit a graph or diagram is poorly understood by students even after completing the topic. Using technology certainly made a difference among my Bachelor of Education students to explore scales in a fun manner. They explored scales when graphing parametric trigonometric functions which created interesting shapes.

![Figure 2: Parametric equations](image)

![Figure 3: Graph of Parametric Equations](image)

![Figure 4: Window Setting for Figure 5](image)

![Figure 5: Graph based on Figure 4 setting](image)

![Figure 6: Window Setting for Figure 7](image)

![Figure 7: Graph based on Figure 6 setting](image)

The activity started by providing each student a graphing calculator and showing Figure 2 followed by Figure 3 projected on a screen in class. Then the students were asked to guess the shape displayed. All the students claimed that the graph was too small to make out the shape. This then led to request for suggestions on how to make the graph bigger. The first response was ‘zoom-in’, but when they tried it, it proved to be futile. Then one student suggested changing the scale. Hence I taught them to use the window settings. Students then explored various scales and had discussions as to how to produce a bigger fish. The activity became more interesting to the students when they saw a fish instead of a boring line graph. The students had fun trying many different scales and very quickly grasped how to make the graph bigger or smaller. They also learnt to change the range so that the graph was in the centre of the screen. The power of the technology is obviously due to the distribution of cognition over the graphing calculator and the student. While the graphing calculator took over the cognitive process of producing and positioning the graph according to the scales and range keyed in, the students focused on how to adjust the scale to obtain a maximum size graph to fit the screen and to adjust the range to centre the graph on the screen.

Giving students then a graph on paper which occupied a small corner of the graph paper immediately produced responses commenting on the inappropriateness of the scale and range and intelligent suggestions were made confidently and accurately to reconstruct the graph to fit the entire page and position the graph more centrally. Hence Pea’s (1985) claims that over time the user will develop cognitive skills to accomplish many of the cognitive processes demonstrated when using technology and would be capable of demonstrating these skills without any longer requiring the aid of the technology proved to be valid.

In the above lesson the interest of the pupils was drawn because the content was transformed in a way that made it intellectually accessible to the students, that is, effective Technological Pedagogical and Content Knowledge had been employed to conduct an innovative lesson which had a great impact on pupils’ learning of scales. The meaningful understanding of the knowledge that the students had acquired when using the technology enabled them to apply it even without the use of technology. If the students had been merely provided with the graphing calculator and asked to construct line graphs according to structured instructions as provided in the graphing calculator guide book on how to draw graphs, the lesson would replicate the traditional instructional practice and would have made no impact on the learning process. Hence the effectiveness of the use of the technology lies in the teacher's Technological Pedagogical and Content Knowledge and not solely on the technology.
Using the CBR to Understand Distance-Time Graphs

This activity focused on the use of the Calculator Based Ranger (CBR) a data collecting device to enhance lower secondary students understanding of distance - time graphs. The first part of the lesson allowed students to explore distance - time graphs using the CBR. Students were instructed to walk at different speeds and observe the graphs displayed on the screen. This enabled them to deduce that the steeper the slope the greater the speed. They also realised that a horizontal line represented no change in distance from the ranger and a negative gradient graph indicated starting away from the CBR.

The second part of the lesson involved interpreting and re-creating given graphs. Students were challenged to produce graphs like the ones given in Figure 8 using the CBR. The process of discussion to produce the graphs demanded a sound understanding of the distance-time graph. Students were soon able to reason out how to produce the challenging graphs and also why some of the graphs were impossible to produce.

![Figure 8: Challenging and Impossible Graphs](image)

The final activity of the lesson challenged students to produce a horizontal graph as shown in Figure 9, with a person moving.

![Figure 9: Horizontal Graph](image)

Their experience when trying to produce a circular graph in the earlier activity enlightened them on producing the graph by rotating the CBR and walking in a circle to produce a horizontal line graph with the person moving. Another group of brilliant students went on to tie the CBR at one end of a metre rule and position one group member at the other end. They walked the group member about the class to produce a horizontal graph. They explained that as long as the distance between the CBR and the group member was constant, the graph would be a horizontal line because time was passing but there was no change in distance.

Again in this activity, the distribution of cognition between the technology and the students enabled the students to focus on understanding the distance-time graphs, rather than been bogged down to merely constructing the graphs from meaningless tables of values. Hence technology provided a means for a teacher to present the content in a way that made it intellectually accessible to the students and hence produced an innovative lesson for the understanding of distance-time graphs. Again application of effective Technological Pedagogical and Content Knowledge to design instruction created an innovative lesson which equipped students with knowledge which they would be able to apply even without the technology, that is, to be able to interpret distance-time graphs and determine which distance-time graphs are possible and why.

Using Dynamic Geometry Software to Understand the Formula for Area of a Triangle

![Figure 10: Dynamic geometry software to obtain the formula for the area of a triangle](image)

This activity started with a rectangle displayed on the screen. The rectangle was drawn using the software. The students who were lower secondary school students were requested to recall the formula for area of a rectangle that they had learnt in
the primary school. The software was used to measure the length and breadth of the rectangle and the students were requested to calculate the area using their formula. Their answers were then checked using the software which displayed the area in square centimetres as shown in Figure 10. Then dividing the rectangle into two equal parts produced two right-angled triangles. Students were asked to suggest a formula for each of the triangles and explain their formula. They reasoned that the area of each triangle was half the area of the rectangle. Hence the area of the triangle formula was obtained. To further investigate if their formula for the area of triangle was correct, they were instructed to drag the sides of the rectangle and record the changing values of the dimensions (length, breadth and area) of the rectangle and triangle. They then calculated the area of the respective triangles from the values of the length and breadth using their formula for the area of triangle and compared their worked out answers with the data displayed. This assured the students that their formula for area of triangle was correct.

The next part of the activity was to help students to realise that the area of a triangle remains unchanged as long as the height and base remains unchanged and that this is irrespective of the shape of the triangle. For this the diagram in Figure 11 was created. Point A moves on the line PQ and the two line segments PQ and RS are parallel. The perpendicular distance AD is the height of the triangle. The students realised that as long as the height and the length of the base remained unchanged although the perimeter changed with the shape of the triangle. Then dividing the rectangle into two equal parts produced two right-angled triangles. Students were asked to suggest a formula for each of the triangles and explain their formula. They reasoned that the area of each triangle was half the area of the rectangle. Hence the area of the triangle formula was obtained. To further investigate if their formula for the area of triangle was correct, they were instructed to drag the sides of the rectangle and record the changing values of the dimensions (length, breadth and area) of the rectangle and triangle. They then calculated the area of the respective triangles from the values of the length and breadth using their formula for the area of triangle and compared their worked out answers with the data displayed. This assured the students that their formula for area of triangle was correct.

Finally students were asked questions on paper to find the area of given triangles and all the students were able to answer all the questions without any difficulty.

The technology sped up the exploration process by taking over the process of drawing and measuring the triangles with a ruler. Hence, the distribution of cognition between the technology and the students enabled the students to focus on discovering and understanding the formula of the area of a triangle rather than been told the formula or merely cutting out one triangle and assuming that the formula fits all triangles. They were also able to explore and realise that the area of a triangle can be calculated using any of the sides as the base as long as the corresponding height was substituted in the formula. Again the use of technology equipped students with knowledge that could be applied even without the technology. The activities using technology enabled the creation of an innovative lesson for discovering and understanding the formula for area of a triangle by the use of effective Technological Pedagogical and Content Knowledge.

Using Dynamic Geometry Software to Demonstrate Application of the Isometries of the Plane in a Creative Manner

In the teachers’ training institutes in Malaysia, students are required to demonstrate application of the isometries of the plane in a creative manner by producing an Escher type tessellation in their Geometry course. When students use the paper medium they produce simple uninteresting geometrical figures because of the difficulty to cut paper shapes accurately and paste them as desired. The process to produce an Escher type tessellation can also be time consuming in the paper medium.

Teaching and learning the isometries of the plane using a dynamic geometry software equipped the students with a tool that made it convenient for them to demonstrate their creativity when applying the isometries of the plane to produce an Escher type tessellation. Figure 12 shows an example of a motif which was created from a square using translation.
The motif in Figure 12 was then translated using appropriate vectors to cover the plane (see Figure 13).

In this activity the teacher shared her technological and content knowledge through her Technological Pedagogical and Content Knowledge with her students. The students having acquired the skill to use the technology to perform the isometries of the plane were able to apply these skills and concepts to be creative. The students’ ideas were expressed clearly because the thinking process of the student was aided by the available cognitive tool (the dynamic geometry software).

Hence creativity was possible because of the distribution of cognition over the student and the available tool. Technology took over a large part of the cognitive process which involved menial steps (such as drawing, cutting and pasting shapes). This afforded the students more time to focus on applying the learnt mathematical knowledge, in this case the isometries of the plane.

In this example, TPACK of the teacher equipped the students with both, the content and technological knowledge. Hence this activity in addition to presenting the content in an intelligently accessible way, also educated the students to use technology to apply the knowledge acquired in a creative manner.

Conclusion
The use of technology to produce innovative instructions can be demonstrated. However, the effectiveness of the technology lies in the teacher's Technological Pedagogical and Content Knowledge. For a teacher to be able to use technology effectively in lessons, he or she must have the required technological knowledge. Then using the acquired technological knowledge in collaboration with pedagogical content knowledge will determine the extent to which the content of the lesson is presented in an intellectually accessible manner to the students and then and only then can the technology have a great impact on the students learning process.

References


