CHEMISTRY TEACHER PROFESSIONAL DEVELOPMENT USING THE TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK) FRAMEWORK

Temechegn Engida
UNESCO International Institute for Capacity Building in Africa (IICBA)
Addis Ababa, Ethiopia
temechegn@gmail.com

ABSTRACT

The knowledge base for teaching was considered to be the pedagogical content knowledge (PCK) conceptualized in the mid-1980s. But with the advent of modern technologies, information and communication technologies (ICTs) are becoming part of the day-to-day life of teachers and students. It was thus argued in the mid-2000s that the knowledge base for teaching in the 21st century is the technological pedagogical content knowledge (TPCK/TPACK). As such TPACK is not a professional development model; rather it is a framework for teacher knowledge. We have thus developed and validated an ICT-enhanced teacher development (ICTeTD) model and the corresponding standards and teacher training modules based on the TPACK framework. This paper demonstrates this innovative model with examples from Chemistry. *[AJCE 4(3), Special Issue, May 2014]*

INTRODUCTION

The development of ICTs in teacher education institutions has been one of the key strategic priorities of UNESCO-IICBA for Africa. With the advent of ICTs and the development of a knowledge-based society, IICBA firmly believes that teacher's role needs to be redefined in a way that meets the demands of 21st century education. To this end, IICBA looks beyond professional teacher development programs that merely focus on training teachers in the operation of computers and ICT literacy per se, and plans to work actively towards enabling African teachers to master ICT as an effective tool to improve teaching and learning and actually integrate their skills in day-to-day classroom instruction and beyond. The issue is no longer whether teachers should integrate technology in their practices, but how to use technology to transform their teaching with technology and create new opportunities for learning [1].

There have been many approaches to introduce ICT into education in general and teaching and learning processes in particular. In the past and even present time there have been five general approaches to technology integration in education. These are [2]:

1. *Software-focused initiatives* such as the mathematical learning and general problem-solving skill development through students' use of the programming language Logo and also the software-based integration attempts made use of integrated learning system software, which provides individualized instruction while tracking students' learning needs and progress.
2. *Demonstrations of sample resources, lessons and projects* such as classroom-based and student-tested examples of appropriate technology use with the assumption that successful use of instructional plans and educational resources is easily transferable among different classrooms.

3. *Technology-based educational reform efforts* such as the larger-scale, often grant-funded, projects that are usually organized around new visions for learning and teaching that are supported by the acquisition of hardware and software.
4. *Structured/standardized professional development workshops or courses* such as large-scale professional development initiatives that are structured either as cascading professional development or as a wide variety of licensed professional development courses to districts, regions, or states, so that teachers can pursue them in more individualized ways.
5. *Technology-focused teacher education courses.* Teacher education institutions, either colleges/universities or districts/regions working alone or collaboratively, offer educational technology courses to teachers, delivered online or face-to-face. These can serve as recertification courses taken on an unclassified student basis or as elements of graduate or undergraduate programs in education.

These technocentric approaches tend to initiate and organize their efforts according to the educational technologies being used, rather than students' learning needs relative to curriculum-based content standards, even when their titles and descriptions address technology integration directly [2]. In other words, they all lack proper consideration of the integration of content and pedagogy. However, in recent years, the technological pedagogical content knowledge (TPACK) framework has emerged as a representation of the knowledge required to use technology in an educational setting in ways that are contextually authentic and pedagogically appropriate [3].

THE TPACK FRAMEWORK

It is now well known, and perhaps well accepted, that the knowledge base for teaching in the 21st century is the technological pedagogical content knowledge (TPCK, later referred to as TPACK for ease of remembering it as a word). The framework was proposed [4] as depicted in figure 1.

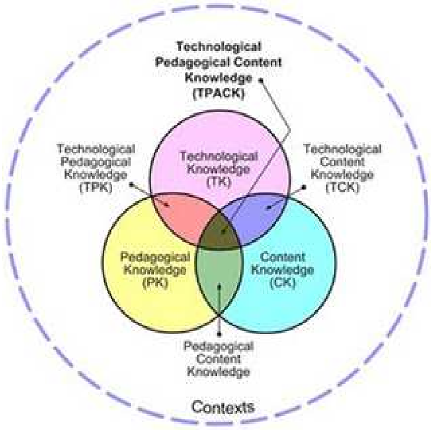


Figure 1. Technological Pedagogical Content Knowledge framework [4, p. 1025]

As Mishra and Koehler [4] argued "though Shulman's approach [of the PCK as the knowledge base for teaching] still holds true, what has changed since the 1980s is that technologies have come to the forefront of educational discourse primarily because of the availability of a range of new, primarily digital, technologies and requirements for learning how to apply them to teaching" (p. 1023). It thus became natural to propose for the integration of technology with PCK, resulting in the amalgam knowledge called the technological pedagogical content knowledge (TPCK/TPACK). The TPCK framework "emphasizes the connections, interactions, affordances, and constraints between and among content, pedagogy, and technology. In this model, knowledge about content (C), pedagogy (P), and technology (T) is central for developing good teaching. However, rather than treating these as separate bodies of knowledge, this model additionally emphasizes the complex interplay of these three bodies of knowledge" [4, p. 1025].

However, TPACK is not a professional development model; rather it is a framework for teacher knowledge [2]. Planners of professional development for teachers may use it by illuminating what teachers need to know about technology, pedagogy, and content and their interrelationships. More importantly, the TPACK framework does not specify how this should be accomplished, recognizing that there are many possible approaches to knowledge development of this type.

Some attempts were made to determine the effectiveness of the TPACK framework in teacher training programs. For instance, one study [5] examined the development of TPACK in four in-service secondary science teachers as they participated in a professional development program focusing on technology integration into K-12 classrooms to support science as inquiry teaching. The study introduced to the science teachers such tools as probeware, mind-mapping tools (CMaps), and Internet applications like computer simulations, digital images, and movies. The researchers then concluded that the intervention program had positive impacts to varying degrees on teachers' development of TPACK. Contextual factors and teachers' pedagogical reasoning affected teachers' ability to enact in their classrooms what they learned in the program.

Another study [6] examined pre-service teachers' perceived knowledge of TPACK and cyberwellness through structural equation modeling. The study also examined the relationships among Singaporean pre-service teachers' perceptions of the constructs pertaining to TPACK, and their perceived ability to integrate cyberwellness knowledge when designing web-related learning. At the conclusion of the study, the researchers argued that the pre-service teachers' confidence to integrate their cyberwellness knowledge into their teaching may play an important role in influencing how they plan and design web-based learning. Cyberwellness knowledge may be an important knowledge component to foster when considering the future development of teachers' TPACK for web-based learning.

There are, however, some theoretical arguments made by some researchers and practitioners who are not finding the TPACK framework completely effective in their work with teachers. Some among these are Krista Moroder [7] and those who expressed their agreement to her blog posted on 3 November 2013. Whereas Moroder agrees with the notion that TPACK looks at the collaboration between technology, pedagogy, and content and that teachers need knowledge of all three, she does not agree with how this framework is presented.

THE ICT-ENHANCED TEACHER DEVELOPMENT (ICTeTD) MODEL IN CHEMISTRY

The ICT-enhanced teacher development model [1] is thus developed as one of the approaches for the professional development of teachers at all levels (including higher education instructors) recognizing TPACK as the knowledge base for teachers and as the backbone of the ICTeTD. The ICTeTD model (figure 2) is expected to serve as the guide for the preparation of pre-and in-service teachers for the 21st century. The tetrahedral framework recognizes and indicates the progressive, transformed and dynamic nature of TPACK. It conveys the transformed nature of TPCK from its constituent content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (PK). Furthermore, the entire knowledge base for teachers is embedded within a context.

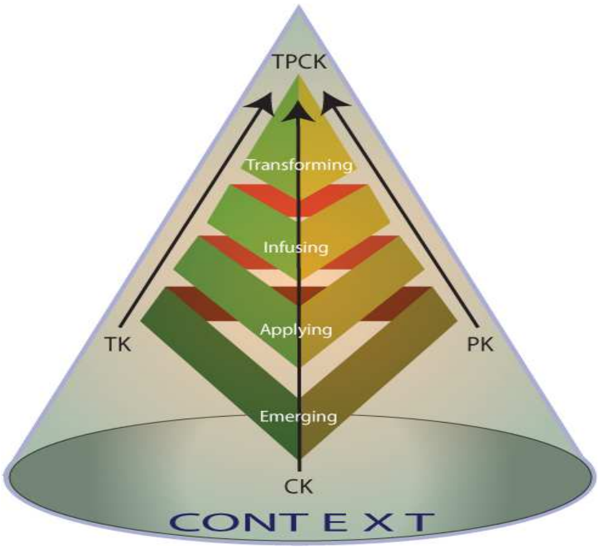


Figure 2. ICT-enhanced teacher development model [1, p. 19]

As can be seen from figure 2, TK and PK are in the plane of the page whereas CK is outward (towards the reader) of this page. All the three knowledge areas are at the same level of (have equal importance) forming the pyramid. The pyramid is made of ‘fleshes’ of TPCK--a transformed knowledge through proper interactions of CK, PK and TK.

The continuum of transformed knowledge (TPCK/TPACK) in figure 1 is categorized into four interrelated stages of development, namely *emerging TPCK*, *applying TPCK*, *infusing TPCK* and *transforming TPCK [1]*. It should be understood that each stage in the figure represents a continuum of triangular faces/planes of the pyramid parallel to its base, and that the space between successive stages is added merely for visibility of the three dimensional model.

***Emerging TPCK* in Chemistry** represents an initial stage of TPACK development by chemistry teachers. Teachers at this stage are beginning to be aware of the nature and importance of TPCK in their social, personal and professional development. In accordance with the ICT-enhanced teacher standards for Africa—ICTeTSA—[8], teachers at this stage are expected to be aware of the importance of a given TPACK chemistry activity (*knowledge*), to review various approaches to that given TPACK chemistry activity (*skills*), and to simply develop interest in using that activity (*attitude*).

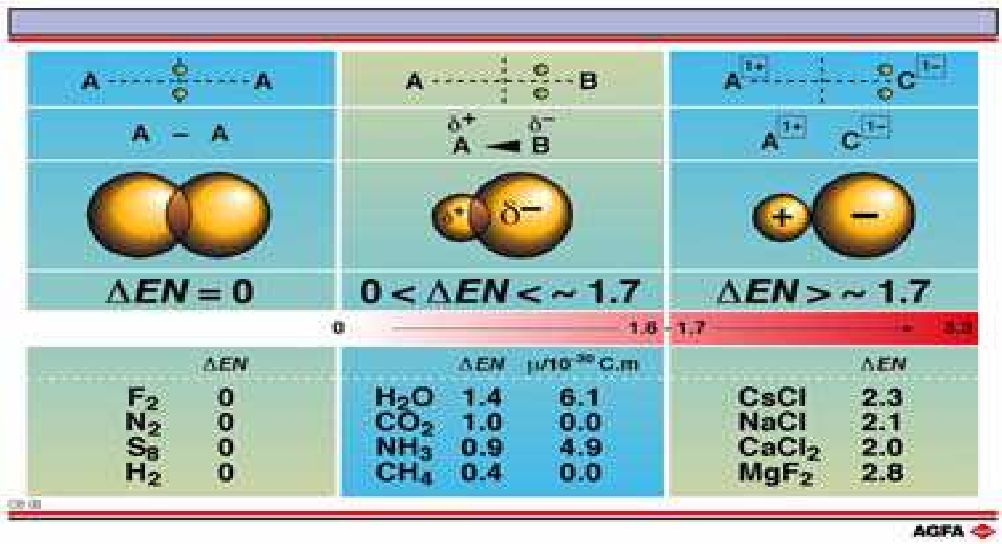
The emerging TPCK stage in Chemistry can be applied using various technological tools like Microsoft word, Excel, PowerPoint, document camera, etc. Let's say that you have taught the States of Matter in the previous sections of your period and now it is time to teach (as per the Chemistry curriculum) the structures of simple organic molecules like methane, ethane, propane, etc. The usual way is to present the nomenclature and their structures on the chalk board (which is a two dimensional object—2D). It is, however, learnt through chemistry education research that most students could not understand the three dimensional (3D) nature of the structure of the molecules. Furthermore, it is time consuming for the Chemistry teacher to draw the structures every time he/she wants to teach/review the structures for different sections of a grade level.

At the emerging stage, the teacher is expected to have the skills of preparing a powerpoint presentation (ppt) such as for simple organic molecules. The length of contents of the lesson can be increased at any time depending on the particular topic you are teaching. What is important here is that, when using the ppt (technological knowledge) in the classroom, you should point out that students usually misunderstand the structures drawn on chalk boards and in some textbooks as being 2D (pedagogical knowledge) rather than 3D (content knowledge).

It is also possible to prepare a ppt for use as an assessment tool. Let's assume that a Chemistry teacher wants to know to what extent his/her students understood the content he/she has taught them regarding the States of Matter. One way is to prepare a ppt involving pictures of actual objects and ask them to write down their responses on a sheet of paper when each slide is shown to the whole class. Note that such an approach can accommodate a large number of students in one class as long as the ppt is visible to every student.

In addition, you can use transparencies prepared by others. One example is the UNESCO & IUPAC chemistry teaching material entitled DIDAC. See the following examples extracted from that material. These slides can be copied/ printed onto overhead transparencies and be used for teaching in the Chemistry classroom.

Example 1: The link between the differences in electronegativity and the type of bonding



Beware!

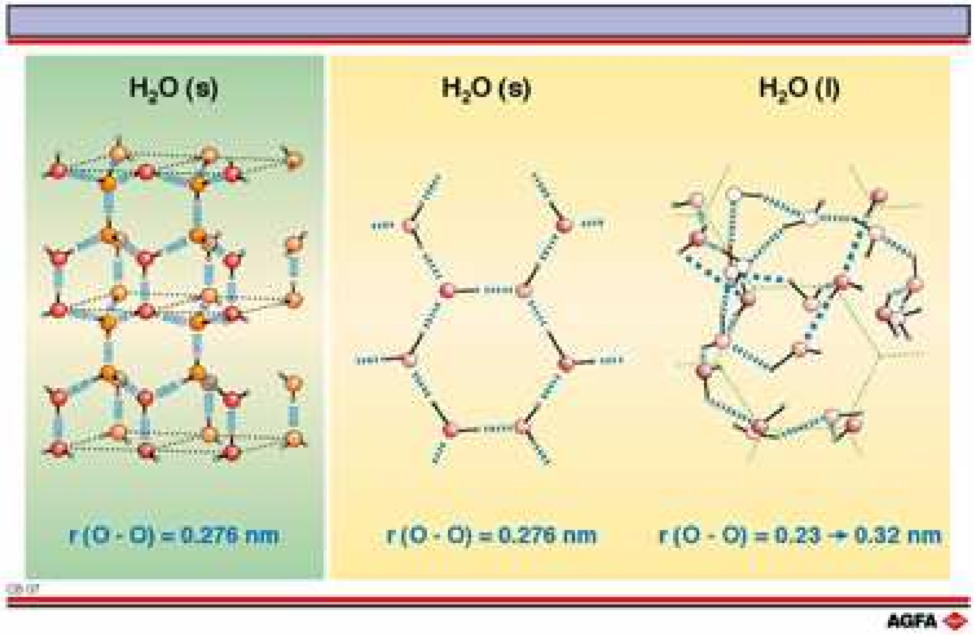
- Substances built up of molecules which have clear polar bonds e.g.

H_2O, NH_3, CO_2, CH_4 do not necessarily behave as polar substances.

- It is possible that the various polar bonds in a molecule cancel each other out, or as it were, "neutralize" each other.
- The direction and charge of the dipole moments generated by the polar bonds has to be taken into consideration, as does the resulting dipole moment for the whole molecule.

- CO_2, for example, is an apolar molecule with two polar bonds between the C and O atoms, each having opposite dipole moments. H_2O and NH_3 are polar molecules, CH_4 is apolar.
- Nonetheless, all of these compounds contain polar chemical bonds.

Example 2: Structure of water as an example of hydrogen bonding



Left side, the three-dimensional representation of the structure of ice:

- The lattice contains a hexagonal structure. Each water molecule has four neighbors in a tetrahedral configuration.

⇒ A very open structure that has a very low density.

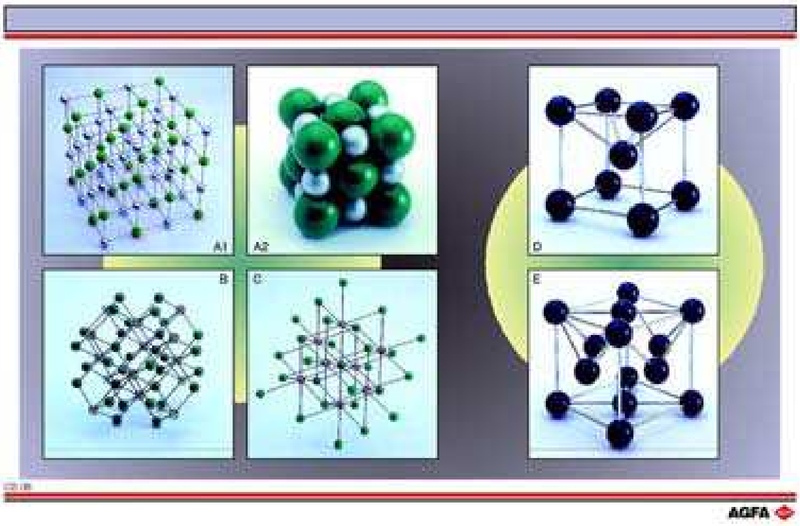
- When it is warmed (to 4° C) the hydrogen bonds are partially broken resulting in a denser structure. On further warming the thermal agitation of the water molecules increases and the density again decreases.

Right side compares the structure of ice with the structure of water at a given instant in time (computer simulation):

- The hexagonal pattern of ice is shown by a light green dotted line
- The blue dotted line represents the hydrogen bonds. The shorter the distance between the dots the shorter the hydrogen bond.
- The color of the oxygen atom indicates to what extent it is out of the plane: white atoms are in the plane whilst dark brown atoms are between 0.7 and 1.0 nm in front of the plane. The light pink and red atoms are at an intermediate distance; the darker the color the further the atom is in front of the plane.

Hydrogen bonds are essential for the spatial configuration of biologically important molecules such as proteins.

Example 3: Lattice Structures



Ionic Lattices

A1 = NaCl (open structure)

A2 = NaCl (close-packed structure)

B = CaF_2

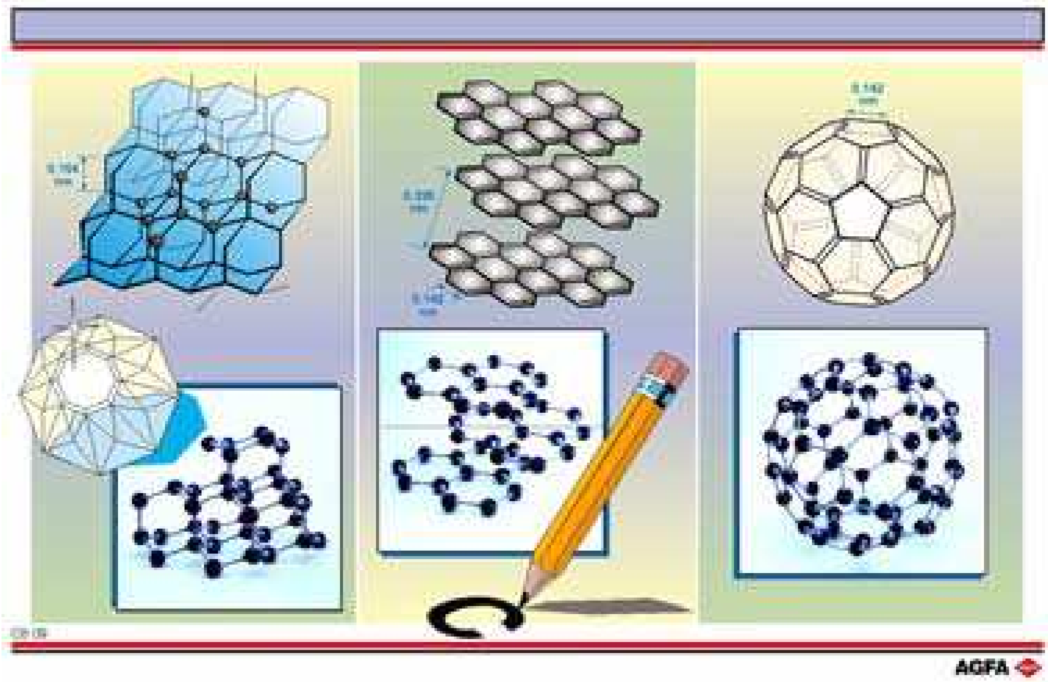
C = CsCl

Metal Lattices

D = Fe (bcc unit cell)

E = Cu (fcc unit cell)

Example 4 : Allotropes of Carbon: Diamond, Graphite and Fullerenes



Diamond (left):

- Each atom is bonded via sp3-hybrid orbital to four atoms in a tetrahedron.
- All four valence electrons are paired in bonding orbitals.

⇒ Diamond is stable, being an insulator with a high melting point and the hardest substance on earth. It is transparent and has a high refractive index.

Graphite (middle):

- Each atom is bonded to another three atoms by sp2-hybrid orbitals.

- Consists of layers of flat, hexagonal rings of carbon atoms. The layers are held together by London force. They slide easily over each other.

⇒Graphite is a soft, black material and is used as a lubricant.

- Each atom contributes three valence electrons to the three s-bonds. The fourth electron forms a π-bond with a neighboring atom. This is not a localized bond but it moves freely throughout the π-system.

⇒ The electrical conductivity parallel to the layers is high, but is low perpendicular to the layers.

Fullerene, C_{60} (right):

- This molecule consists of 60 carbon atoms divided into 20 six-rings and 12 five-rings, like a football.
- In 1996 Robert F. Curl, Sir Harold W. Kwoto and Richard E. Smalley received the Nobel Prize for chemistry for this discovery.

***Applying TPCK* in Chemistry** is characterized by teachers who started to use TPCK-based programs/lessons developed by others. Chemistry teachers at this stage also start engaging themselves in discourses among themselves about what it means to be a teacher of TPCK-based Chemistry curriculum, about their feelings and students' feelings while experiencing the TPCK-based curriculum, etc. In accordance with the ICT-enhanced teacher standards for Africa—ICTeTSA—[8], teachers at this stage are expected to recognize and describe the approaches for a given TPACK chemistry activity (*knowledge*), to use available approaches that are claimed by the authors for that given TPACK activity using ICTs in the specified chemistry area (*skills*), to evaluate the appropriateness of that given TPACK activity for their target learners (*skills*), and to demonstrate positive attitudes in using that activity developed by others and that promote the standard in their subjects using ICTs (*attitude*).

In the applying stage teachers use ICT for professional purposes, focusing on improving the teaching of Chemistry so as to enrich how to teach with a range of ICT tools. The applying stage is linked with institutions in which a new understanding of the contribution of ICT to learning has developed. In this phase, administrators and teachers use ICT for tasks already carried out in institution management and in the curriculum. Teachers still largely dominate the learning environment.

Let's assume that you want to teach the topic Elements and Atoms to your students. Apart from preparing and using a PowerPoint presentation by yourself, as in the case of the emerging TPCK, you can also download from the Internet lessons that teach the topic and prepared with screenshot software and you can project it to the classroom. Such materials have also audio components that the students can listen to. You can stop the multimedia lesson at any time if you want to emphasize a certain point in the lesson and/or if you want to ask questions that the student could predict/hypothesize before listening and watching the next segment of the recorded lesson.

As part of the Chemistry teacher training lessons, a group of teachers separately watch the downloaded Chemistry lesson, compare and contrast the use of the lesson in a group-work-learning format, compare the pedagogical strategy and the specific technology used with their own practices in teaching the topic for the target learners. Such training activities constitute the knowledge component of the competencies expected of the teachers. With regard to the skills component of the competencies for the applying level of ICTeTSA [8], a group of Chemistry teachers can prepare lessons of their own on Elements and Atoms using a specific lesson plan templates, incorporate the videos and slides of their own by recording their practices on a group of students using a video camera. The teachers could also develop positive attitude towards this particular TPACK activity by evaluating and discussing the lessons recorded by other course mates.

Note that you will be able to develop your own such lessons as your technological knowledge is advancing. Perhaps your will do so when you reach the infusing TPCK stage in teaching Chemistry, but for sure you can do it at the transforming stage.

***Infusing TPCK* in Chemistry** represents a stage of TPACK development by teachers who started to modify, adapt and initiate their own TPCK-based materials/lessons/modules for diverse group of learners. Teachers at this stage have the capability to mentor/advise other teachers about what and how of TPACK-based chemistry educational programs. They can also comfortably adapt themselves to new situations in those programs. They can design and carryout TPACK-based inquiry/research activities to solve personal and institutional problems.

In the infusing stage, Chemistry teachers infuse ICT in all aspects of professional life to improve student learning and the management of learning processes. ICT enables teachers to become active and creative in stimulating and managing the learning process, by infusing a range of preferred learning styles and uses of ICT in achieving educational goals. Chemistry teachers are required to master authoring tools, animation tools and multimedia tools to develop instructional software in Chemistry. In accordance with the ICT-enhanced teacher standards for Africa—ICTeTSA—[8], teachers at this stage are expected to explain and criticize the pros and cons of various approaches for a given TPACK chemistry activity in terms of established theories, appropriateness of ICT tools, content requirements (pedagogical approaches) within a

Chemistry area and contextual factors (*knowledge*), to produce what is needed by the standard using ICTs for their subject areas and target groups (*skills*), to use one's produced standard-based TPACK chemistry activity for the target group (*skills*), to evaluate the effectiveness and efficiency of one's produced approaches for that given TPACK activity (*skills*), and to appreciate the care and rigor needed in implementing the standard for target learners using available ICT tools (*attitude*).

For instance, at the infusing TPCK stage, a Chemistry teacher starts designing his/her own lessons by using free software available for educational purposes. One such software is the Advanced Chemistry Development (ACD/ChemSketch). As stated in the reference manual [9], ACD/ChemSketch is a chemical drawing software package from ACD/Labs designed to be used alone or integrated with other applications. ChemSketch is used to draw chemical structures, reactions, and schematic diagrams. It can also be used to design chemistry-related reports and presentations.

ACD/ChemSketch has the following major capabilities: **Structure mode** for drawing chemical structures and calculating their properties, **Draw mode** for text and graphics processing, and **Molecular Properties** calculations for automatic estimation of: Formula weight, Percentage composition, Molar refractivity, Molar volume, Parachor, Index of refraction, Surface tension, Density, Dielectric constant, Polarizability, Monoisotopic, nominal, and average mass.

ACD/ChemSketch can stand alone as a drawing package or act as the "front end" to other ACD/Labs software such as the NMR Predictor engines. Once ACD is installed in the computer (TK), the Chemistry teacher can follow the instructions/user manual for drawing and animating (PK), for instance, the structures of organic molecules (CK). The animated structures with different models such as wire frame, sticks, ball and sticks, space filling, dots only, and discs can be used to challenge students' misconceptions about the structures of the molecules through the teacher's application of this particular TPACK activity.

Transforming TPCK in Chemistry is the highest stage of social, personal and professional development of 21st century teachers. Teachers at this stage are creative and innovative in that they not only develop new and appropriate TPCK programs for their institutions but also theorize about the nature and methodologies of TPCK. In accordance with the ICT-enhanced teacher standards for Africa—ICTeTSA—[8], chemistry teachers at this stage are expected to master the approaches and techniques that promote the given standard within and across grade levels of Chemistry as well as across the institute's/school's curricula using ICTs (*knowledge*), to demonstrate creativity in relation to that particular standard using ICTs in their institutions/schools and beyond (*skills*), and to demonstrate motivation, dedication and sensitivity to implementing the standard to various target groups using ICTs (*attitude*).

The transforming stage is linked with institutions that have used ICT creatively to rethink and renew their institute. ICT becomes an integral part of daily personal productivity and professional practice. The focus of the Chemistry curriculum is now much more learner-centered and integrates the subject in real-world applications, both in real and virtual environments. For example, students may work with community leaders to solve local problems related to water by accessing, analyzing, reporting, and presenting information with ICT tools. Learners' access to technology is broad and unrestricted. They take even more responsibility for their own learning and assessment. ICT is taught as a subject area at an applied level and is incorporated into all vocational areas. The institution has become a centre of learning for the community. Teachers need to master special software, learning management system, simulation and modeling tools, networking and various web tools, in order to innovatively transform the teaching and learning system.

At this stage, the teacher is a creative and innovative person. He/she can design, implement and evaluate a range of technological tools in teaching Chemistry and across the curriculum. At this stage the teacher should be able to design Chemistry website at least using opensource software like Joomla. He/she should also be able to use the content management software like Moodle for wider and online learning.

SUMMARY

Base on the ICTeTD model [1] and the corresponding standards [8], we developed a training module for Chemistry (of course to other subjects like History, Geography, Biology, Mathematics, Physics, and Literacy (we can do so for any subject in the curricula of any level, K-University). The basic idea behind these documents is that (chemistry) teacher training in the 21st century needs to be designed in such a way that they develop technological, pedagogical content knowledge (TPCK/ TPACK) as one package if they are to be successful and effective teachers. In addition, as teachers and their contexts vary to a great extent, there is a need for a progressive development which we classified as *Emerging TPCK*, *Applying TPCK*, *Infusing TPCK and Transforming TPCK*.

The training of chemistry teachers will follow activity-based interactive lessons, with each lesson designed to implement the approach depicted in figure 3. Facilitators of the training of teachers will follow what is called the lesson study approach. Lesson Study is a teaching improvement process that has origins in Japanese elementary education, where it is a widespread professional development practice. Working in a small group, teachers collaborate with one another, meeting to discuss learning goals, to plan an actual classroom lesson (called a "research lesson"), to observe how it works in practice, and then to revise and report on the results so that other teachers can benefit from it. The lesson study employs PDCA (plan–do–check–act or plan–do–check–adjust) approach which is an iterative four-step management method used in business for the control and continuous improvement of processes and products.

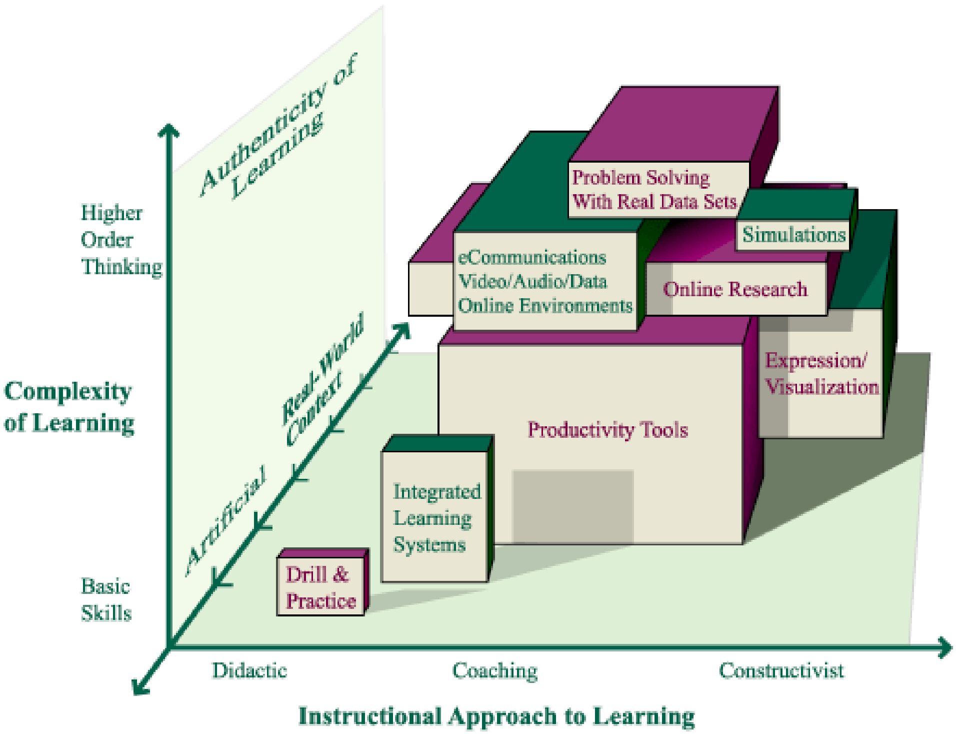


Fig. 3: A 3-D representation for gauging which instructional approach with ICT (X-axis) might support students' thinking (Z-axis) in authentic learning situations (Y-axis)[10]

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