Asian Journal of Chemistry; Vol. 25, No. 1 (2013), 377-380

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2013.13079

Creative Chemistry Teaching

M. JAHANGIRI and R. HAJIAN*

Gachsaran Branch, Islamic Azad University, Gachsaran, Iran

*Corresponding author: E-mail: hajian@iaug.ac.ir; hajian@ch.iut.ac.ir

(*Received*: 18 November 2011; *Accepted*: 28 July 2012) AJC-11882

In the present paper, a strong call is issued to reconsider the teaching methods used by teachers in general and chemistry teachers in particular. The study makes an attempt to derive the widely-applicable and practical teaching procedures so as to logically indicate the probabilistic directions in which chemistry teaching has to proceed. For this purpose, specific reference is made to the notions of creativity and problem-solving and the fact that true learning is deeply rooted in these psychological concepts. In the end, creativity is redefined and its critical role, which has often been ignored, is reincorporated in the teaching profession. Specific guidelines are presented to introduce this psychological concept in chemistry classes.

Key Words: Graduate education/research, Chemical education research, Curriculum, Interdisciplinary/multidisciplinary, Problem-solving, Student-centered learning.

INTRODUCTION

Chemistry or chemical education is a comprehensive term that refers to topics related to the study or description of the teaching and learning of chemistry in schools, colleges and universities. Topics in chemistry education might include understanding how students learn chemistry, how best to teach chemistry and how to improve learning outcomes by changing teaching methods and appropriate training of chemistry instructors, within many modes, including classroom lecture, demonstrations and laboratory activities (Wiki). Dr. Robert L. Lichter, then-Executive Director of the Camille and Henry Dreyfus Foundation, speaking in a plenary session at the 16th Biennial Conference on Chemical Education (recent BCCE meetings)[1,2], posed the question "why do terms like 'chemical educator' even exists in higher education, when there is a perfectly respectable term for this activity, namely, 'chemistry professor.' One criticism of this view is that few professors bring any formal preparation in or background about education to their jobs and so lack any professional perspective on the teaching and learning enterprise, particularly discoveries made about effective teaching and how students learn. (Wiki). Finally, there is an emergent perspective called The Scholarship of Teaching and Learning (SoTL)[2]. Although there is debate on how to best define SoTL, one of the primary practices is for mainstream faculty members (organic, inorganic, biochemistry, *etc*.) to develop a more informed view of their practices, how to carry out research and reflection on their own teaching and about what constitutes deep understanding in student learning[3]. Lippincott, a former editor, stated the Journal's aims well: "to provide chemistry teachers with information, ideas and materials for improving and updating their background and their understanding of the science and for helping them in their teaching and in their effectiveness in developing the talents of students.

The question of choice from among and arriving at the most effective method for teaching chemistry has always been a topic of interest in academia with no apparent settlement. Controversy surrounding the most effective method can be traced to two features. First, researchers have too often taken the meanings of such terms as "success" and "learning" for granted thus failing to prepare the groundwork required for the discussion. Secondly, genuine chemistry abilities have neither been formally identified nor catered for. As a result, there has seldom been a trustworthy yardstick by means of which to assess the success of a student's attempt at learning chemistry and his/her potential for future research projects. Bloom identifies the following six categories in the order of decreasing complexity in learning[4]:

Bloom's taxonomy category description: Judging (Evaluation): Student appraises, assesses and criticizes based on specific criteria and standards.

Key Concepts: Judgment, Selection.

Sample Questions: What is your opinion? Do you believe?

Creating (synthesis): Student originates, combines and integrates ideas into a product or plan that is new to him or her.

Key concepts: Divergence, productive thinking, novelty.

Sample questions: Can you think up? How can we improve?

Analyzing (analysis): Student relates the hypotheses and evidence with the thought process he or she is using.

Key concepts: Logic, induction and deduction, formal reasoning.

Sample question: What is your conclusion?

Solving (application): Student resorts to data and principles to complete a problem or task.

Key concepts: Solution, convergence, application.

Sample question: If…Then… solve for…

Understanding (comprehension): Student understands and interprets information based on prior theory.

Key concepts: Explanation, Comparison, Illustration.

Sample question: Describe…

Remembering (knowledge): Student recalls or recognizes facts and ideas.

Key concepts: Memory, Knowledge, Repetition.

Sample questions: Who…What…Where…When…Why …Define…

Hestenes puts teaching into new perspective and light differentiating "conceptual learning" from "wrote learning"[5]. He states that conceptual learning is "creative", "systematic" and "contextual". He also believes that conceptual learning depends on "conceptual tools" and "critical feedback". Phillips maintains that " In the United States, the trend over the past five years has been to use problem-based learning techniques to solve real-world problems in analytical chemistry classes"[6]. He points out that laboratory exercises can be used to emphasize the skills employers deemed important. Taber[7] and Moore[8] consider the commonality between chemistry and other branches of science. Taber maintains that "common perceptions of the relationship between chemistry and physics as neighbouring scientific disciplines may be over-simplistic"(p. 103). Moore[8] reports on "resourceful approaches "taken by those doing modern chemical research citing research melding inorganic chemistry, materials chemistry, biochemistry, molecular biology and electrical engineering.

As of yet, there is no body of literature that specifically addresses and remedies the learning problems that students face in the course of learning chemistry and how theses problems and the subsequent lessons learned from them can be utilized to enhance the spirit of creativity, self-esteem and self-confidence required to dare to attempt scientific endeavors which push the frontiers of science outwards.

Reber[9] defines creativity as "…mental processes that lead to solutions, ideas, conceptualization, artistic forms, theories or products that are unique and novel" while Corsini[10] views creativity as the "ability to apply original ideas to the solution of problems; the development of theories, techniques, or devices,…." It can be seen that uniqueness, originality and problem-solving techniques are the quintessence of creativity. In other words, a creative mind always tries to develop and explore new ways of solving a problem. In technical terms, a creative mind is more of a parallel circuit than a serial one being equipped with a variety of ways to solve the problem. This parallelism in creative and critical thinking as the core of learning enables the learner to shift perspectives with self-confidence not solely relying on textbooks or the instructor. This study confirms the significant and central role creativity can play in enhancing the conceptual learning of chemistry while providing specific information on an area where there is limited research available. The main objectives of the creative chemistry teaching are four-fold: (i) To create creativity among chemistry teachers and students. (ii) To indicate the research avenues in which to proceed. (iii) To establish self-confidence as a direct offset of obtaining creativity and enhancing chemical insight, to foster independence and to individualize learning. (iv) To systematically prioritize the course material subjects and to suggest the priority sequence for teaching chemistry subjects thus providing the chemistry teacher with a tool to assess his/her level of intelligibility at any time in the course of teaching.

Tenets of the creative chemistry teaching

Needs creation, ideation and motivation: As the creative chemistry teaching is mainly a problem-based approach, the teacher has to explain as clearly as possible setting a clear learning goal for students. As opposed to traditional classroom procedures where the student assumes a highly passive role imitating the input and material provided by the teacher or the text (level 1 in Bloom's Classification), the creative chemistry teaching, as a student-centered approach advocates the fact that needs are to be created/felt in the minds prior to teaching. These needs can be identified through the establishment of industrial links with chemical industries. In sum, the idea or the purpose of learning chemistry should originate from the students and not the text or the teacher and the teacher only leads the students supplying information only when they need it. Wenden[11] points to the reluctance on the part of students to assume responsibilities for their learning quoting

Schoenfeld (1982) has noted that many enter the classroom completely unaware that they can observe, evaluate and change their own cognitive behaviour….It has not occurred to them that they might be able to be actively involved in their own learning." Wright shares the same belief when saying[12]: "…a need exists to move from the passive learning styles that have characterized chemistry courses to an active style in which students participate and assume responsibility for their learning".

It appears that creativity is one of the most effective ways to cope with our ever-changing learning environment. This is the essence of the constructivist view in education encapsulated in Piaget's maxim[13]: "To understand is to invent." The automaticity and the low level of self-confidence and creativity among some students studying chemistry may be traced to the verbatim memorization, acceptance and regurgitation of course content and the fact that some chemistry students may consider course content as absolute gospel with almost no selective reading and changes allowed. Many chemistry teachers' experience that some students in traditional chemistry classes are not capable of developing or discussing a topic beyond the range of topics covered in the class. To remedy for this situation, the students are taught how to creatively contribute to the class discussions and to dynamically shape their own mental framework. This is exactly where needs are felt by the students at which time the teacher supplies the necessary feedback. The chemistry teacher should motivate and enable the students to feel the need to learn and ask questions rather than his/her own. The students' questions should arise from a genuine desire to learn more and to fill the information thirst. The teacher's questions should lead to more questions on the part of the students if they are ever to be asked. These questions should be minimally above the students' level of present knowledge as assessed by Bloom's classification of learning so as to encourage creativity leading them to take care of their own learning experience.

Identification of prerequisites and priorities: The chemistry teacher should prioritize course content. He/she should make sure students know the background material necessary to get involved in the new subject. If they do, what is their level of learning in terms of Bloom's Classification (ranging from 1-6 in increasing order of complexity). If they don't, what is the optimal level of learning required to undertake the new topic. He/she should determine, in advance, the logical path along which old information (already existing in the students' mind) has to be connected to new information being processed (the lesson). For instance, to teach how a Raman instrument operates, he/she has to have provided the students with the background concerning autochromatic light sources, collection optics, Rayleigh scattering, optics to filter Rayleigh scattering, spectrometer and detectors. More than that, the prerequisite lessons should also be prioritized to facilitate the flow of ideas. Hudspeth *et al*., advocate the use of a portable Raman instrument as a visual aid[14]. They state that "Having portable Raman instrumentation would allow the instructor to demonstrate the principles of Raman spectroscopy, as well as the concepts of calibration curves, blank subtraction, detection limits and regression analysis.

Every learning task can be broken down into its building blocks or subtasks whose completion leads to the final task. New terminology needs to be introduced here to act as a springboard for this discussion. A hexavalent learning task is defined here as one whose completion requires performance on all the six levels of learning in Bloom's classification. These are: repetition, interpretation, application, logic, creation and evaluation. To invent a machine, one's mind obviously has to operate at levels 5 and 6. To remember Gas Laws or the date of the final exam, level 1 would suffice (univalence). To solve a chemical problem, one has to apply his/her knowledge. Thus, the mind should operate at level 3 or trivalent application. Also, to do a 3d visualization of the bonding angles one has to be creative to some degree. This is exactly where interactive web sites make self-paced learning an enjoyable experience. In an experiment with chemistry students enrolled in an English For Specific Purpose (hence ESP) course, the author found 91 % of students only using the base level or repetition as their main operating level of learning. Seven percent used both level 1 and 2 to learn the subject matter (bivalence). Only about one per cent of the students could operate at the level of applying their gained knowledge with debilitating anxiety and lack of self-confidence making it impossible for the students to perform at higher levels. In fact, the rise of this method of teaching chemistry came in part as a reaction against the inaccuracies, shortcomings and lack of dynamics associated with traditional classes. Fig. 1. shows a schematic representation of the learning levels as a pyramid whose base corresponds to the most basic level (the largest proportion) of learning taking place. Consider the following:

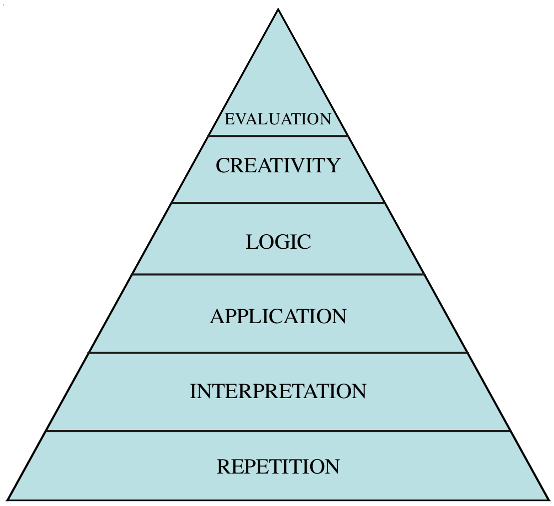

Fig. 1. Learning pyramid as a graphical representation of bloom's classification

When these subtasks interact the valency might change as a result of the interaction. For instance to repair a car one can replace a part. Understanding the operation of an individual part might require a hexavalent learning task but to repair the car the mechanic does not have to go into that detail just replacing the defective part. Subsequently, the valence of the whole lowers as the task becomes more complex. Likewise, one does not have to know everything about the mechanics of a car to drive it. These build a network of dependency relationships whose understanding and prioritizing helps enhance chemical insight. The phenomenon can be represented in matrix form with each row indicating a level and each entry a binary digit (0 or 1) representing the exigency of a level of learning. Thus

$$\begin{vmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 1 \end{vmatrix} + \begin{vmatrix} 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{vmatrix} + \begin{vmatrix} 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{vmatrix} + \begin{vmatrix} 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{vmatrix} = \begin{vmatrix} 0 \\ 0 \\ 3 \\ 4 \\ 4 \\ 4 \end{vmatrix}$$

Subtask1 Priority1 (t1) Subtask2 Priority2 Subtask3 Priority3 Subtask4 Priority4 End task

The end task matrix (hence ETM) is helpful in that it is indicative of the complexity of the end task. Here, the end task makes the least demands on creativity and evaluation as the entries are 0's in both cases, while there is a high degree of repetition, comprehension and logic involved. One can utilize this learning matrices (LM) to gain insights into the nature of the end task and how to handle the learning problem at hand.

Class flow pattern: The following stages are to be performed in consecutive order to achieve optimal results.

Motivation stage: This is the stage at which the teacher asks warm-up questions brainstorming the subject making it interesting. He/she has the students form groups of two or three sitting in circular layout thus encouraging them to engage in teamwork and cooperation and removing psychological barriers as debilitating anxiety and fostering self-confidence and expression. He/she informs the students of the objectives of the lesson, its applications, industrial needs and the market for the chemistry topic they are introduced to. Students learn through similarities and differences. If the teacher has as his/her teaching objective Raman spectroscopy's weak and strong points, the optimal way to contextualize and illustrate it would be to compare and contrast its scattering effect, microscopy and imaging against those of IR absorption.

The identification of priorities and the sequencing of content.

The specification of the students' or the student's level of learning using the level-identifying questions or LIQ's.

Proceeding to the next level and modifying teaching material in accordance with the new level.

Sample creative chemistry teaching lesson plan introducing chemometrics

Class flow pattern

Motivation stage: Talk about the history of chemometrics, the need for that, its importance in analytical chemistry in particular and today's world in general and its applications so as to interest students. Introduce highly interactive internet sources offering 3d visualization.

Prioritization of course content: Priority 1: Multidimensional datasets

Sample questions or LIQ's: Define chemometrics! (Level 1: Repetition). Who introduced the term? (Level 1: Repetition). What are multidimensional datasets? (Level 1: Repetition). What are their (dis)advantages as compared with 1D-data? (Level 1: Repetition).

Hint: Teach multidimensional datasets through comparison and contrast with 1D and 2D data to make the subject intelligible.

Priority 2: White, Black and Gray Systems

Sample Questions Or LIQ's: Describe the characteristics of these systems! (Level 2: Understanding And Interpretation)

Priority3: Signal Processing Techniques

Sample questions: Describe the aims! (Level 2: Understanding And Interpretation). Define SNR! (Level 1; Repetition).

Wavelet

Sample questions: Define a wavelet! (Level 1: Repetition). Compare and contrast wavelet transform with Fourier Transform! (Level 2: Understanding). Can you think of potential applications for chemometrics in environmental analysis and forensics? (Levels 3 and 4: Application and Analysis). Can you think up a relation between neural networks and chemometrics (Level 6: Creativity).

Conclusion

In this paper, an attempt has been made to show how creativity and critical thinking can be assessed and applied to chemistry classes. The ability to think critically is a crucial aspect in academia. This ability is a hallmark of university education. It was argued that a creative class has certain advantages over a conventional teacher-centered one.

There seems little doubt that the range of positions advertised in the local press by the employers requires strong chemical insight and inventiveness on the part of chemistry graduates who fill them. Given that creativity contributes to educational success, an attempt was made here to accommodate it into a teaching method of chemistry whose foundations rest on Bloom's learning classification.

The paper sought to address, in some detail, the strategies that can be of potential use in creative teaching and critical thinking in chemistry in regard to situating the present research within the framework of the existing body of research. However, we do not claim more for the notion than it deserves. The tentativeness of these strategies is only in part due to the fact that research on the teaching methods of chemistry is still in progress. While the fuzziness and in determinacy surrounding teaching methods are recognized here, the main claim of the paper is that in the currently under-researched field of chemistry teaching, it has tried to make the foundations clearer. It is hoped that, at least, some reformulation of the research topic has now been made possible and while the research is continually expanding from on-going work, observations would carry the seeds of future avenues of research broadening our view of academic performance and success in chemical education.

REFERENCES

1. E.D. Siebert and W.J. McIntosh, College Pathways to the Science Education Standards Arlington, VA: NSTA Press, p. 57 (2001).
2. B.P. Coppola, *J. Chem. Educ*., **84**, 1902 (2007).
3. B.P. Coppola and D. Jacobs, In eds.: M.T. Huber and S. Morreale, Is the Scholarship of Teaching and Learning New to Chemistry? Disciplinary Styles in the Scholarship of Teaching and Learning. A Conversation. Washington DC: American Association of Higher Education and the Carnegie Foundation for the Advancement of Teaching, p. 197 (2002).
4. B.S. Bloom, Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook I. Cognitive Domain-NY: David McKay (1956).
5. D. Hestenes, *Am. J. Phys*., **71**, 104 (2003).
6. D.N. Phillips, Teaching Analytical Chemistry Through Mineral Analysis, Analytical Chemistry, p. 427 (2002).
7. K.S. Taber, *Chem. Educ.: Res. Pract.*, **4**, 103 (2003).
8. J.W. Moore, *J. Chem. Educ*., **81**, 455 (2004).
9. A.S. Reber, Dictionary of Psychology, London: Penguin Books, p. 172 (1995).
10. R.J. Corsini, Dictionary of Psychology, London: Brunner/Mazel, p. 234 (1999).
11. A.L. Wenden, *TESOL Newsletter*, **19**, 7 (1985).
12. J.C. Wright, *J. Chem. Educ*., **73**, 827 (1996).
13. J. Piaget, To Understand Is To Invent, New York: Grossman, p. 15 (1973).
14. E.D. Hudspeth, D. Cleveland, K.L. Batchler, P. A. Nguyen, T.L. Feaser, L.E. Quattrochi, J. Morenz, S.A. Balram, J.X. Zhou, D. Lombardi and R.G. Michel, *Spectrosc. Lett*., **39**, 99 (2005).