Building a Democratic Model of Science Teaching

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Abstract: Earlier in the last century, learning in science, as was learning in other disciplines, was developed according to the philosophy of behaviorism. This did not serve the purposes of learning in science properly, as the students were forced to absorb information transferred from the main and the only source of learning, the teacher. Towards the end of the century a significant shift from behaviorism to constructivism philosophy took place. The shift promoted the development of more democratic models of learning in science which provided greater opportunities to the students to act as real scientists, chattering for the building of knowledge and scientific skills. Considering the characteristics of science and the characteristics of the students as active learners, the shift towards democratic models of learning is unavoidable and is merely a matter of time.

Keywords: science education, models of learning, behaviorism, constructivism.

Extensive efforts have been invested for the development of effective teaching in science, and this pursuit has become a serious area of study for many science education experts and researchers all over the world, at least since the middle of the last century. Shocked by the success of their Russian counterparts in launching the first man-made satellite, Sputnik, the whole army of western scientists, mainly the Americans, were

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then aware that there must be some weaknesses in the development and implementation in the teaching of mathematics and science in their schools. The success of the Russians in leading the western world in the space science and technology competition was generally perceived as a strong indicator of the superiority of their education system, mainly in science, compared to the systems then implemented in the western world. Not long after that a number of science education projectsmainly for the improvement of curriculum and teaching methodology in pre-college level-were launched for the pursuit of more effective models of instruction (Duschl, 1990: 22). The main and the ultimate goal of these projects was to develop and promote more effective teaching models in science, where process and product of teaching were regarded as having equally important roles in the development of student understanding of science. The promotion of this paradigm was expected to improve the students' learning competence and skills.

Along with the primary goal mentioned above, the project planners were also interested in developing public perception that science was a promising and interesting subject, so that more potential students were interested to take it as their major, and at the end prominent scientists would be available in greater number to face the challenges of the pursuit of hegemony in science and technology. Projects like Physical Science Study Committee (PSSC), Chemical Education Materials Study (CHEM-Study), Biological Science Curriculum Study (BSCS), Harvard Project Physics, and Science Curriculum Improvement Study (SCIS), were just a few examples to name, which were established to support the pursuits of greater control in science and technology development.

The impacts of the above projects and of other projects with similar goals have influenced many aspects of the teaching of science, spread out literally globally, for many years following the years of the establishment of the projects, and provoked other nations to take the same actions. However, the results of the efforts still left a number of questions of whether the very core of the goals of the efforts, i.e. to promote better and more effective science as process and product was really acquired. This question rooted out from the reality that regardless of the implementation of teaching practices according to already up-graded curriculum, which was also supported with better laboratory facilities, the students seemed to have not sufficiently, and actively involved themselves in the process of learning. There were indications that the students neither really devoted their time, nor concentrated their minds to the process of development of meanings of what they were studying. To a significant extent, this might be caused by the general situation of classroom instructionin science and other fieldsin which the students usually did not have enough and adequate opportunity to actively involve themselves in the process of learning and development of knowledge. As the consequence the students usually did not have adequate learning skills and became very dependent to the main and traditional learning resource in the classroom, i.e., the teacher.

Among the arguments frequently adopted to refuse or to argue against innovations in science instruction is the need to fulfill the target of the curriculum, i.e. to cover all of the topics listed in the curriculum in a given period of schooling, which is usually considered too short. This maxim causes teaching-learning process in science classes to become so poor that the process component of science learning is almost totally absent. The efforts are usually concentrated on covering all the possible topics, as soon as possible, with a great portion of time devoted to solving the problems related to the topics, mainly those with complex mathematical treatments. In such a situation there would never be enough time to give adequate opportunity to the students to undergo an appropriate process of learning.

In Indonesia, for example, the above situation has been promoted by a pressing need to prepare students, especially General Senior High School (SMU) students to compete with their counterparts for the limited seats of higher level of education. In this climate, it would be impossible to explore and develop the students' learning ability, and the efforts of making use of what they have learnt previously in their learning would not be useful. Not only because time is limited and the needed learning resources and equipments are in poor conditions, but the will or commitment to develop and to implement an innovative, more appropriate and democratic learning environment is not there. Science has become literally an instructive subject. However, it is well understood that to create an environment of learning which encourage student self-inquiry and promote appropriate mechanism of development of student understanding is not an easy task. Besides it is time consuming, it needs a total support of school policy, teachers' competence and commitment, learning resources and equipments, and appropriate culture of student learning.

SCIENCE AS PROCESS AND PRODUCT

It has been publicly accepted in the world of science education, that science consists of process and product.These two aspects should not be separated from each other if science is expected to function as it should. Accordingly it is recommended that teaching of science should contain appropriate proportions of both content and process in which students are given enough opportunity to carry out inquiry in order to develop their understanding. Science teaching approach which focuses merely on 'mapping the nature' should be abandoned as it is not in accordance with the natural character of science itself and denies students' opportunity to operate as active learners. In this approach of instruction, learning is viewed as accepting well constructed knowledge from the available learning resources which in practical term are usually represented by the teachers. No place for arguments, even when the delivered knowledge is producing contradictory perceptions in students' minds. The main product of this model of science teaching is a 'map of the nature' from which the students are expected to describe what the nature is, what components constitute the whole entity of the nature and how all the components interact with each other to maintain all the 'live processes' as the nature has been operating so far.

Wittrock (1977) in Osborne and Fryberg (1985: 83) viewed that as active learners students must themselves actively construct or generate meaning from their sensory inputs, such as sights, sounds, smells and so on. These assumptions are developed from an array of arguments supporting the thesis that students are not passive receivers of knowledge, but on the contrary of this conservative attitude, students are creators of human description of the nature. A number of writers in learning, such as Kelly (1977), Osborne and Wittrock (1983; 1985), and Landfield and Leitener (1980), strongly argued that learning should be viewed as active construction of meanings from the external stimuli, or as a process of hypothesis construction and testing, or a process of construction of meaning and validation. Accordingly in a classroom interaction the students should be treated as such that their natural ability of processing information is facilitated and the end results of their learning have a strong relationship with their already existing cognitive structure. According to this theory, students will follow a number of steps in their action for generating knowledge. First, the students will naturally activate their instruments of censoring when there is an input from the external world to interact with the already existing cognitive network in their minds. Second, as knowledge is not transferred intact will all the attributes related to it, the students will generate meaning of the newly accepted information. Third, the newly formed meaning will undergo a process of assessment in the students' minds to determine whether it has an opportunity to be logically related to the already existing cognitive structure, and yield a meaningful description. Fourth, if successful, a further process takes place to assess if it is not contradictory to the students' long term memory. Fifth, the new concept is integrated to the previously existing knowledge structure of the students. This last step expands the capacity of the students' cognitive structure, which means an improvement of the students' ability to carry out more challenging learning tasks.

Unfortunately, students' self construction of science often leads to misconceptions, in which the understanding of concepts developed by the students are different from those generally understood by scientists, or those formally accepted in the scientific community. It social sciences, this phenomenon might be tolerated, at least to a certain extent, as social sciences are open to personal interpretation and subject to cultural biases. Natural sciences do not have the luxury of free interpretation as there are restrictions of their compulsory relationship to the real nature. Epistemologically, development of natural sciences must fulfill the criteria of correspondence, which is different from the criteria of truth commonly adopted in social sciences and in mathematics, i.e pragmatism and consistence.

Because of its uniqueness, a model of teaching with some specific characters is needed in science. On one hand the model should be able to facilitate the potential of the students to construct their own knowledge, while on the other hand it is also required to keep the students' construction inside a restricted territory that the criteria of truth related to the developed understanding is fulfilled. Leave alone the two extremes of teacher-student interaction modes, the highly structured and the totally unstructured approaches, science teaching models should be designed as such that the content and process components are appropriately facilitated.

FROM BEHAVIORISTIC TO CONSTRUCTIVISTIC APPROACHES

In its development science teaching approach has been following a track which is in accordance with the development of psychology of learning. Changes of thought in psychology of learning show a gradual and continuous shift from the basic assumption which views a learner as a passive acceptor of information to active constructor of knowledge. In the terminology of psychology of learning the shift is a shift from the behavioristic to the constructivistic approach. In between these two extremes there are concepts which regard learning as dependence of psychological development. The real shift from regarding learners as passive acceptors of knowledge to active constructors of meaning of the nature was pioneered by Bruner and other writers in the early seventies of the last century, in the forms of discovery learning, and concept acquisition or concept formation models of learning (Ibnu, 1987).

Behavioristic approach to education was introduced long ago by a number of educators of the past such Thorndike, Skinner, and Watson. However, a real model in science teaching related to this approach was first formulated by Gagne in the early sixties (Neuman, 1993: 87). Behavioristic approach is based on the view that learning is simply an effort to develop relationships between incoming stimuli or signals to the brain and responses or behavioral outputs. Newborns are regarded as having blank cognitive slate, where the teachers can write what they want the children to learn. It is suggested that a specific input should predictably and reliably result in a specific output by the learner because stimuli and responses are connected by strong bonds. Therefore teaching materials should be so structured that connections can be easily developed in the children minds. In Gagne's term the content of teaching should be transferable in a hierarchical structure, starting from the simple elements to the more complicated ones. The complexity itself should be deliberately developed that at any step a logical connection can be identified.

Regardless of its significant impacts to science teaching in its era, a series of modifications, or improvements have been introduced by its supporters, which results in a conclusion that learning cannot be regarded simply as a stimulus (S) and response (R) model, but a more complicated mechanism must take place in student minds. The most prominent contribution of this model to science education is probably the stimulus it gave to the emergence of other models which accommodate many more important factors determining the success of student learning. Although it is not totally abandoned, its role in science education has been gradually taken over by more recently developed models.

Different from the behavioristic approach, which views learning as a mechanistic instructional action done by the teachers to the students, the cognitive approach of learning tends to define learning as something which is influenced by human minds. Insight, desire, activity, and perception are psychological elements regarded as important factors influencing the act and the results of learning. It is suggested that human mind develops in a predetermined natural sequence, influenced by the quality of the individual's life experiences and by the neural maturation of the human brain. It is also believed that newborns enter the world with a set of neural connections. This set makes up the initial structure of human mind. As the youngsters confront their worlds, various experiences change their mental structures. This process of incorporating new perceptions into an individual's cognitive structures is called learning (Neuman, 1993: 89).

In the cognitive view, learning materials should be so organized that learning can happen productively in accordance with the students' cognitive structure. Denial of this will make learning fruitless. It means that student cognitive maturity should be used as the criteria to determine the levels of complexity and difficulties of the learning materials. It implies that the students can only learn materials which are parallel to their psychological maturity, as only learning tasks with approppriate levels of complexity which can be facilitated by their cognitive structure.

In the early seventies of the last century, Bruner introduced a more student active model of learning (Ibnu, 1987). This model, which is called discovery learning, is based on an assumption that students are naturally active learners. On confronting a new situation they will spontaneously form a perception. However this perception, or meaning, is only temporarily retained until an opportunity to validate it can be executed. The validation stage is very critical in the development of knowledge. A positive validation will support the students to reinforce the understandings they developed earlier, or otherwise they will discard whatever they believed as correct in the former stages, if the validation is not supporting the believes they formerly developed.

The essence of discovery learning is the radical shift from the basic assumption that students are passive recipients to active builders of knowledge, and that they play the most important roles in knowledge building. Without active involvement of the students, development of understanding of new phenomena will be much harder for them. Instead of development of true understanding, rote learning will be more likely to happen in the absence of mental involvement of the students.

In the years following the learning paradigm shift in the part of the students' role, many more writers in learning theory took the same side for advocating learning models which gave the students more and more significant roles in learning. The move to the philosophy of constructivism started to come into its real shape. In this case the theory of meaningful learning (Ausubel et al, 1978), and the theory of generative learning (Osborne & Wittrock, 1983; 1985), were among the most strongly advocated in that period.

Although it was not explicitly stated as a model of constructivism, Ausubel et al (1978) argued that learning happened because of the effort of the students to confer the meaning of the newly encountered phenomena to their cognitive structure. Through the concept of advance organizer it is advocated that only perceptions which can be related to the already existing cognitive structure of the students which have the opportunity to be held as product of learning. Other perceptions unrelatable to the students' cognitive structure would simply be remembered for a short period before being discarded. It means that only meaningful perceptionsin relation to the students' cognitive structurewhich would be retained and added to the structure. The new structure which is now richer than before will have a greater capacity to facilitate further learning, and it also means that the students are having a better capacity to undertake harder or more complex learning tasks.

About two decades before the end of the last century, the development of constructivism in learning theories, particularly in science education, culminated in the theory of generative learning (Osborne & Wittrock, 1983; 1985). This theory views learning as consisting of two main components: the act of development of meaning of the encountered phenomena, or stimuli, and the act of assessing whether the newly developed meanings are acceptable to the cognitive structure of the students, which is represented by the students' short term and long term memories. It can be stated that this theory is a blend of two other theories of learning previously formulated, i.e., the discovery learning developed by Bruner and his colleagues and the meaningful learning which was primarily developed by Ausubel and friends. For many science educators this theory seems to be the best theory so far developed as it harmoniously accommodates two important characteristics of the learners, which in the earlier theories were taken as the bases of two different disciplines of thought: the 'Brunerian' and the 'Ausubelian'. As discussed earlier, the first stream of thought views the students as 'aggressive' creators of knowledge through the mechanism of meaning development and validation, while the second tends to view the students as wise accommodators of new understandings of the encountered phenomena, after a deep consideration and assessment against the already existing organizer.

In the concept of generative learning students are regarded as 'freedom limited agents of meaning developers'. When a student is having an encounter with a new situation, spontaneously he or she will scan the incoming information before making a decision whether the process of meaning development should be continued or terminated. This step is made because the student is not totally free to execute the act of development of meaning to the newly encountered phenomena. It is the student's short term and long term memories which influence the student's ability to develop meanings of the newly encountered phenomena. If the act of meaning development is facilitated, the process of learning will continue. Otherwise, it will terminate and the newly received information will be simply bounced back without causing further steps of learning to take place. The next step of learning, following 'the acceptance' of the information is the assessment of the newly developed meaning, using a kind of comparation procedure, against the student's cognitive structure. Again, in this step, the students' short term and long term memories will play their roles. If the newly created meaning is successful to pass this stage it will be added up the already existing cognitive structure, which in turn will enlarge the capacity of the students to undertake the future learning tasks. Failure in any step to pass the assessment mechanism will cause the half-processed information to be discarded.

Regardless of its success in accommodating the interests of the two different schools of thought, in the view of true constructivism there are weaknesses which can be identified as generic to the generative model of learning. On one hand this theory puts forward the active roles of the students as developers of knowledge, while on the other hand it restricts the possibility of the development of meaning by the introduction of the limiting short term and long term memory structures making up the students' cognitive construct. The restriction of the students' learning capacity seems to be prematurely introduced, as the theory states that even the possibility of new information to be taken as fresh stimuli to learning is restricted by the existence of short term and long term memory arsenals of the students. The danger relatable to this situation is that the formed meaning doesn't directly reflect the true meaningthe characters or the propertiesof the observed objects or phenomena, but tends to be influenced by the students' experiences which are not always dependable as the basis of learning process undertaken by the students. In Glaserfeld's words, it's sad that if constructivism, particularly radical constructivism, is adopted in such a way that constructive activity must happen in every learning, there will be no knowledge as the result of it. The products of constructive activities would be different from one student to the other, while at the same time a truth would be always a truth, regardless whether there is an activity of construction or not. It's called "... an attempt to cut loose from the philosophical tradition that knowledge has to be a representation of reality" (Osborne, 1996: 56). On the criticism on social constructivism, other writers wrote social constructivists portray the world as being full of peculiar symbolic entities as atoms, electrons, ions, fields, genes and chromosomes, which only meaningful if the perception of these things and their interrelationships have been properly constructed by the students.

Considering the above criticisms and the expectation that learning in science should end-up in the mastery of process and content on the learners' side, there is a need for the development of a teaching model which provides great opportunity to the students to optimize the use of their learning capacity, while at the same time give an assurance that the result of the activity is in accordance with the truths so far, and generally accepted as truths, by the scientific community. In other words the students should have sufficient freedom to actively involve themselves in the creation of knowledge, and the results of the creation do not contain unacceptable misconceptions.

THE DEMOCRATIC MODEL OF LEARNING IN SCIENCE

The conservative approach usually adopted to ensure the formation of correct understanding is by limiting student interpretation of the incoming stimuli and 'force' a determined understanding, regardless whether it is in accordance with the students' conception or not. This approach will strongly protect the students from making misconceptions which means that the content of science can be transferred to the students' mind almost free from mistakes. However, this approach will certainly create a new problem. The problem is that there is no assurance at all that the students really understand what they learnt. Moreover, if the assumption that students are active learners is accepted, it can be expected that contradictions will emerge in the students' mind as the result of the students' inability to accommodate the prescribed meanings in their cognitive structure. These contradictions might lead the students to react unproductively to other stimuli or improperly use the weakly held understandings, in their future learning. Gilbert, Osborne and Fensham (1982) grimly hypothized that in such a situation, a student might end up with a mixed or confused construction, as there were no reliable prior understandings to be used as the basis for further development of knowledge. Some students might even totally reject to use the newly developed understandings as they were not in accordance with other understandings believed to be correct by the students.

Totally liberal approach on the other hand, will never been applicable in science education. If the approach is meant to provide the students the opportunity to construct meanings of the nature as free as they want, some problems will soon come to surface. First, it will deny the philosophical assumption of science. As was mentioned previously, science follows the philosophy of correspondence as the criteria of truth. However the knowledge was constructed, and however it is described, it should communicate the same meaning of the nature, which is not negotiable except if new facts suggest that new formulations of the phenomena need to be developed to keep the reliability and the accuracy of the information. Second, problem on learning will follow. As in science learning is meant as developing new knowledge on the basis of the already existing scientific or cognitive structure in the students' mind, meaningful learning will never take place as the basis to be used is 'shaggy', and might be different from one student to the other. As the result, learning will be taken as memorizing new information which is not relatable to the knowledge arsenals of the students.

Development and implementation of a new approach of teaching and learning in sciencethe democratic approachseem to be a must. This is not because a compromised solution is needed to solve the problem of polarization in the philosophy of science teaching and learning, but it concerns more to the nature of science itself. As a form of human culture science has been growing from its infancy to its current maturity through a long process. Along the path of its development there were inventions, development of concepts and theories, improvement in its power of predictions, together with some failures, misconceptions, inaccuracy, and incompatibility to the observed data. All these phenomena reflect the dynamic combination of the main constituents of science, i.e. content and process. The development of concepts and theories for instance, reflects the scientists' actions in their efforts to expand their understanding of the nature. The results of the actions were 'content of science' in the form of concepts and theories, and 'process of science', in which the scientists extended and strengthened the methodology they used in their inquiry. In the process of this inquiry the scientists had been exercising the 'democracy in science', where they negotiated with their own knowledge and with the knowledge of their colleagues to develop mutually shared meanings and understandings of the newly encountered phenomena.

The implementation of the principles of democracy in science teaching and learning is expected to result in a strong and deep understanding of the learnt concepts as the learners arrived at the understandings after involving themselves in process of negotiation upon the construction of the understandings. Another important effect expected to evolve from the implementation of the approach is the promotion of scientific skills amongst the students. This is very important in order to develop student competence to operate as young scientists in their learning of science. Mastery of the skills will better facilitate the students to undertake a better and more successful learning process. Following the constructivist theories of learning as those developed by Ausubel et al (1978), Bruner et al (1977), and Osborne & Wittrock (1983, 1985), learning will be more successful if the learners are able to relate the newly learnt phenomena with the cognitive structure they already had in their mind, or if the learners can get through a successful validation for the temporary understandings constructed in the process.

The most important amongst the nurturant effects expected to develop from the implementation of the democratic model of learning is the culture or tradition of democracy in learning. Adoption of the tradition by the students will make them ready to take part actively in the process of further learning, or in the development new knowledge, scientifically and democratically. Tradition of optimizing the use of and negotiation with the already existing cognitive structure will expectedly develop in the students' learning. This will open the whole range of possibility of accepting the meaning of the newly encountered phenomena intact, or changes in the freshly constructed understandings, or even modifications of the already existing cognitive structure.

A number of learning models in science can be classified as democratic models. Or at least the embryos of democratic models. Without discrediting other concepts of learning, including those related to the Piagetian paradigms, three models can be proposed as the representatives of democratic models of learning in science. These are the concept of meaningful learning, as developed by Ausubel et al (1978), the concept of discovery learning (Bruner et al, 1977), and the concept of generative learning (Osborne & Wittrock, 1983; 1985). As extensively discussed elsewhere these models accommodate the mechanisms of construction and reconstruction through a step of validation in the process of development of understanding, which might be done internally or externally. Internal validation optimizes the use of cognitive structure of the students, while external validation uses other people constructions, or other validated data as the standards of truth.

The three proposed models, or the hybrid forms of them are believed to be useful for construction or modification of understanding. In the process of construction negotiations take place between 'correct' understandings constructed by the students in their previous learning, which have become parts of the students' current cognitive structure, with the newly constructed meanings. In this case the newly constructed meanings are validated against the existing cognitive structure. In the process of modification or reconstruction validation takes place another way around, i.e., the newly constructed meanings tend to modify the already existing cognitive structure. In both processes negotiation between the already existing cognitive structure and the newly constructed understandings, signifies the democratic process of the construction of the ultimate understandings. Thus the most essential part of the democratic approach is conserved. Related to the process of correction of misconceptions, the 'three staged models' as the ones developed by Renner et al are the best examples of democratic models. In this models, students with misconceptions in their minds are confronted with new evidences which are not in accordance with their retained conceptions. This situation brings the students to a hesitating condition, and start rethinking about their prior understandings of the analyzed phenomena. When this situation has come to surface the teacher should lead the students to a consolidation phase by offering them with alternativebut correctunderstandings. Reinforcements should then follow to strengthen the newly developed understandings. Giving more examples is one of many ways applicable for reinforcement purposes.

However, some improvements of the models still must be carried out. Overcoming the premature limiting influences of the already existing cognitive structure is one of the needed improvements. This will provide the students with a greater opportunity to access external information or stimuli, so a richer and wider range of inputs can be processed in further stages of learning. It means that the learning capacity of the students is broaden up, the students' academic skills are enhanced, and the process of learning is made more productive.

CONCLUSION

From the above discussions some concluding remarks can be put forward. The development of democratic models in science seems to be a must. The reasons behind this strong statement point more towards the characteristics of science itself as an area of study, and the characteristics of students as active developers of understanding. Combination of the characteristics of science and the students implies in a need of a model of learning which accommodates the 'process and content' character of science and the nature of meaning creator of the students. The three models of learning discussed in previous sections are regarded, at least in parts, as fulfilling the principal requirements of such a model. Some efforts still have to be made in order to get a model which optimizes the strengths, and minimizes the weaknesses of the earlier introduced models, regarded as the embryos of the expected democratic models of learning. Of course, more than one models will expectedly be introduced to the field. This should not provoke a big concern, since the availability of more than one models offers a wider range of choices that the teachers are able to choose a model which is considered as the most appropriate for a certain learning situation.

However, some criteria should be satisfied so that a model can be classified into a democratic model of learning. First, the nature of science requires that the students be given enough opportunity to actively involve themselves in the process of development of knowledge, so that the essential components of science, i.e. content and process, are adequately served. The involvement of the students is not limited in physical terms, such as doing laboratory works or doing observations in the field. Psychological involvement is much more important in the efforts for improving the quality of learning. Second, learning situation needs to be developed as such that student creativity can be optimally exploited to produce a student centered learning. Third, sufficient opportunity should be given to the students to have hands-on experience as much as possible. This of course requires adequate supports in terms of the availability of laboratory equipment and other needed learning media, and fourth, any misconception identified in the process of student construction should be properly treated as soon as possible. The students should be invited to involve themselves in a democratic process of negotiation in order to assess whether their previous constructions of knowledge are tenable or should be modified or even discarded.

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