Course: Foundations of Science Education (8627)

Semester: Autumn, 2020

ASSIGNMENT No. 2

Q.1 Explain Ausubel's theory of learning and its implications for teaching science. What changes in teaching practices you would suggest to apply this theory I teaching of science in our schools?

The behavioral perspective is the psychological approach that suggests that the keys to understanding development are observable behavior and external stimuli in the environment. Behaviorism is a theory of learning, and learning theories focus on how we respond to events or stimuli rather than emphasizing internal factors that motivate our actions. These theories provide an explanation of how experience can change what we do. Behaviorism emerged early in the 20th century and became a major force in American psychology. Championed by psychologists such as John B. Watson (1878–1958) and B. F. Skinner (1904–1990), behaviorism rejected any reference to mind and viewed overt and observable behavior as the proper subject matter of psychology. Through the scientific study of behavior, it was hoped that laws of learning could be derived that would promote the prediction and control of behavior. Russian physiologist Ivan Pavlov (1849–1936) influenced early behaviorism in America. His work on conditioned learning, popularly referred to as classical conditioning, provided support for the notion that learning and behavior were controlled by events in the environment and could be explained with no reference to mind or consciousness (Fancher, 1987). **Classical conditioning** theory helps us to understand how our responses to one situation become attached to new situations. For example, a smell might remind us of a time when we were a kid. If you went to a new cafe with the same smell as your elementary cafeteria, it might evoke the feelings you had when you were in school. Or a song on the radio might remind you of a memorable evening you spent with your first true love. Or, if you hear your entire name (Isaiah Wilmington Brewer, for instance) called as you walk across the stage to get your diploma and it makes you tense because it reminds you of how your father used to use your full name when he was mad at you, then you've been classically conditioned.

Classical conditioning explains how we develop many of our emotional responses to people or events or our "gut level" reactions to situations. New situations may bring about an old response because the two have become connected. Attachments form in this way. Addictions are affected by classical conditioning, as anyone who's tried to quit smoking can tell you. When you try to quit, everything that was associated with smoking makes you crave a cigarette.

Pavlov and Classical Conditioning

Ivan Pavlov (1849–1936) was a Russian physiologist interested in studying digestion. As he recorded the amount of salivation his laboratory dogs produced as they ate, he noticed that they actually began to salivate before the food arrived as the researcher walked down the hall and toward the cage. "This," he thought, "is not natural!" One would expect a dog to automatically salivate when the food hit their palate, but before the food comes? Of course, what happened is that the dogs knew that the food was coming because they had learned to associate the footsteps with the food. The keyword here is "learned."

A learned response is called a “conditioned” response. Pavlov began to experiment with this “psychic” reflex. He began to ring a bell, for instance, prior to introducing the food. Sure enough, after making this connection several times, the dogs could be made to salivate to the sound of a bell. Once the bell had become an event to which the dogs had learned to salivate, it was called a conditioned stimulus. The act of salivating to a bell was a response that had also been learned, now termed in Pavlov’s jargon, a conditioned response. Notice that the response, salivation, is the same whether it is conditioned or unconditioned (unlearned or natural). What changed is the stimulus to which the dog salivates. One is natural (unconditioned) and one is learned (conditioned).

Watson believed that most of our fears and other emotional responses are classically conditioned. He gained a good deal of popularity in the 1920s with his expert advice on parenting offered to the public. He believed that parents could be taught to help shape their children’s behavior and tried to demonstrate the power of classical conditioning with his famous experiment with an 18-month-old boy named “Little Albert.” Watson sat Albert down and introduced a variety of seemingly scary objects to him: a burning piece of newspaper, a white rat, etc. But Albert remained curious and reached for all of these things. Watson knew that one of our only inborn fears is the fear of loud noises so he proceeded to make a loud noise each time he introduced one of Albert’s favorites, a white rat. After hearing the loud noise several times paired with the rat, Albert soon came to fear the rat and began to cry when it was introduced.

Social Cognitive Theory (SCT), originally known as the Social Learning Theory (SLT), began in the 1960s through research done by Albert Bandura. The theory proposes that learning occurs in a social context. It takes into consideration the dynamic and reciprocal interaction of the person, environment, and their own behavior.[1]

Not all forms of learning are accounted for entirely by classical and operant conditioning. Imagine a child walking up to a group of children playing a game on the playground. The game looks fun, but it is new and unfamiliar. Rather than joining the game immediately, the child opts to sit back and watch the other children play a round or two. Observing the others, the child takes note of the ways in which they behave while playing the game. By watching the behavior of the other kids, the child can figure out the rules of the game and even some strategies for doing well at the game. This is called observational learning.

Observational learning is a component of Albert Bandura’s Social Learning Theory (Bandura, 1977), which posits that individuals can learn novel responses via observation of key others’ behaviors. Observational learning does not necessarily require reinforcement, but instead hinges on the presence of others, referred to as social models. Social models are normally of higher status or authority compared to the observer, examples of which include parents, teachers, and police officers. In the example above, the children who already know how to play the game could be thought of as being authorities—and are therefore social models—even though they are the same age as the observer. By observing how the social models behave, an individual is able to learn how to act in a certain situation. Other examples of observational learning might include a child learning to place her napkin in her lap by watching her parents at the dinner table, or a customer learning where to find the ketchup and mustard after observing other customers at a hot dog stand.

Bandura theorizes that the observational learning process consists of four parts. The first is attention—one must pay attention to what they are observing in order to learn. The second part is retention: to learn one must be able to retain the behavior they are observing in memory. The third part of observational learning, initiation, acknowledges that the learner must be able to execute (or initiate) the learned behavior. Lastly, the observer must possess the motivation to engage in observational learning. In our vignette, the child must want to learn how to play the game in order to properly engage in observational learning.

In this experiment, Bandura (Bandura, Ross, & Ross, 1961) had children individually observe an adult social model interact with a clown doll (Bobo). For one group of children, the adult interacted aggressively with Bobo: punching it, kicking it, throwing it, and even hitting it in the face with a toy mallet. Another group of children watched the adult interact with other toys, displaying no aggression toward Bobo. In both instances, the adult left and the children were allowed to interact with Bobo on their own. Bandura found that children exposed to the aggressive social model were significantly more likely to behave aggressively toward Bobo, hitting and kicking him, compared to those exposed to the non-aggressive model. The researchers concluded that the children in the aggressive group used their observations of the adult social model's behavior to determine that aggressive behavior toward Bobo was acceptable.

While reinforcement was not required to elicit the children's behavior in Bandura's first experiment, it is important to acknowledge that consequences do play a role within observational learning. A future adaptation of this study (Bandura, Ross, & Ross, 1963) demonstrated that children in the aggression group showed less aggressive behavior if they witnessed the adult model receive punishment for aggressing against Bobo. Bandura referred to this process as vicarious reinforcement because the children did not experience the reinforcement or punishment directly yet were still influenced by observing it.

Q.2 What are the major tenets of Ausubel and Bruner's theories of learning? What are the implications of these theories for teaching science?

A comparison of the major tenets shared by the three cognitive theories of Piaget, Bruner, and Ausubel, as well as variations in the description of cognitive development unique to each, provides a basis for a global phenomenological dialectical scheme of psychological development in the spirit of Werner. These theories represent points on a dimension from Piaget's particular organismic world-view to Ausubel's tendency towards a mechanistic orientation. Each theory, however, adopts a structuralist approach towards theory and explanation assuming qualitative change in structure over time. Cognitive growth is seen as qualitative changes in thought systems though the source of change is seen variously to be either the properties of the internal structural system itself or the organized system provided by the external environment. Each theory proposes a form of conflict resolution as a critical mechanism of change in thinking, though the form of such change-mechanisms varies from Piaget's stages of internal organization to Bruner's notion of external amplifiers and

Ausubel's subsumption process. The unique and complementary implications these theories have for education are examined. It is proposed that fundamental similarities in accounting for cognitive growth suggest an integration of each special contribution is plausible and useful to educationalists. At the same time, a comparison of the unique and diverse viewpoints of intellectual development which each theory provides may serve to clarify by contrast the particular contribution of each to education.

Bruner (1966) was concerned with how knowledge is represented and organized through different modes of thinking (or representation).

In his research on the cognitive development of children, Jerome Bruner proposed three modes of representation:

- Enactive representation (action-based)
- Iconic representation (image-based)
- Symbolic representation (language-based)

Bruner's constructivist theory suggests it is effective when faced with new material to follow a progression from enactive to iconic to symbolic representation; this holds true even for adult learners.

Bruner's work also suggests that a learner even of a very young age is capable of learning any material so long as the instruction is organized appropriately, in sharp contrast to the beliefs of Piaget and other stage theorists.

Enactive (0 - 1 year)

The first kind of memory. This mode is used within the first year of life (corresponding with Piaget's sensorimotor stage). Thinking is based entirely on **physical actions**, and infants learn by doing, rather than by internal representation (or thinking).

It involves encoding physical action based information and storing it in our memory. For example, in the form of movement as a muscle memory, a baby might remember the action of shaking a rattle.

This mode continues later in many physical activities, such as learning to ride a bike.

Many adults can perform a variety of motor tasks (typing, sewing a shirt, operating a lawn mower) that they would find difficult to describe in iconic (picture) or symbolic (word) form.

Iconic (1 - 6 years)

Information is stored as **sensory images** (icons), usually visual ones, like pictures in the mind. For some, this is conscious; others say they don't experience it.

This may explain why, when we are learning a new subject, it is often helpful to have diagrams or illustrations to accompany the verbal information.

Thinking is also based on the use of other mental images (icons), such as hearing, smell or touch.

Symbolic (7 years onwards)

This develops last. This is where information is stored in the form of a code or symbol, such as **language**. This mode is acquired around six to seven years-old (corresponding to Piaget's concrete operational stage).

In the symbolic stage, knowledge is stored primarily as words, mathematical symbols, or in other symbol systems, such as music.

Symbols are flexible in that they can be manipulated, ordered, classified, etc. so the user isn't constrained by actions or images (which have a fixed relation to that which they represent).

The Importance of Language

Language is important for the increased ability to deal with abstract concepts.

Bruner argues that language can code stimuli and free an individual from the constraints of dealing only with appearances, to provide a more complex yet flexible cognition.

The use of words can aid the development of the concepts they represent and can remove the constraints of the "here & now" concept. Bruner views the infant as an intelligent & active problem solver from birth, with intellectual abilities basically similar to those of the mature adult.

Educational Implications

The aim of education should be to create autonomous learners (i.e., learning to learn).

For Bruner (1961), the purpose of education is not to impart knowledge, but instead to facilitate a child's thinking and problem-solving skills which can then be transferred to a range of situations. Specifically, education should also develop symbolic thinking in children.

In 1960 Bruner's text, The Process of Education was published. The main premise of Bruner's text was that students are active learners who construct their own knowledge.

Readiness

Bruner (1960) opposed Piaget's notion of readiness. He argued that schools waste time trying to match the complexity of subject material to a child's cognitive stage of development.

This means students are held back by teachers as certain topics are deemed too difficult to understand and must be taught when the teacher believes the child has reached the appropriate stage of cognitive maturity.

The Spiral Curriculum

Bruner (1960) adopts a different view and believes a child (of any age) is capable of understanding complex information:

'We begin with the hypothesis that any subject can be taught effectively in some intellectually honest form to any child at any stage of development.' (p. 33)

Bruner (1960) explained how this was possible through the concept of the spiral curriculum. This involved information being structured so that complex ideas can be taught at a simplified level first, and then re-visited at more complex levels later on.

Therefore, subjects would be taught at levels of gradually increasing difficultly (hence the spiral analogy). Ideally, teaching his way should lead to children being able to solve problems by themselves.

Discovery Learning

Bruner (1961) proposes that learners construct their own knowledge and do this by organizing and categorizing information using a coding system. Bruner believed that the most effective way to develop a coding system is to discover it rather than being told by the teacher.

The concept of discovery learning implies that students construct their own knowledge for themselves (also known as a constructivist approach).

The role of the teacher should not be to teach information by rote learning, but instead to facilitate the learning process. This means that a good teacher will design lessons that help students discover the relationship between bits of information.

To do this a teacher must give students the information they need, but without organizing for them. The use of the spiral curriculum can aid the process of discovery learning.

Bruner and Vygotsky

Both Bruner and Vygotsky emphasize a child's environment, especially the social environment, more than Piaget did. Both agree that adults should play an active role in assisting the child's learning.

Bruner, like Vygotsky, emphasized the social nature of learning, citing that other people should help a child develop skills through the process of **scaffolding**.

'[Scaffolding] refers to the steps taken to reduce the degrees of freedom in carrying out some task so that the child can concentrate on the difficult skill she is in the process of acquiring' (Bruner, 1978, p. 19).

He was especially interested in the characteristics of people whom he considered to have achieved their potential as individuals.

The term scaffolding first appeared in the literature when Wood, Bruner, and Ross described how tutors' interacted with a preschooler to help them solve a block reconstruction problem (Wood et al., 1976).

The concept of scaffolding is very similar to Vygotsky's notion of the zone of proximal development, and it's not uncommon for the terms to be used interchangeably.

Scaffolding involves helpful, structured interaction between an adult and a child with the aim of helping the child achieve a specific goal.

Q.3 Write detailed note on roots of Constructivism.

Constructivism is first of all a theory of learning based on the idea that knowledge is constructed by the knower based on mental activity. Learners are considered to be active organisms seeking meaning. Constructivism is founded on the premise that, by reflecting on our experiences, we construct our own understanding of the world consciously we live in. Each of us generates our own "rules" and "mental models," which we use to make sense of our experiences. Learning, therefore, is simply the process of adjusting our mental models to accommodate new experiences. Constructions of meaning may initially bear little relationship to reality (as in the naive theories of children), but will become increasing more complex, differentiated and realistic as time goes on.

Constructivist learning theory does not necessarily imply that one must follow a "constructivist" pedagogical strategy. In other words, most researches firmly believe that knowledge is constructed, but some (e.g. main stream instructional designers) do not adopt an instructional design that is labelled "constructivist".

Typically, a constructivist teaching strategy is based on the belief that students learn best when they gain knowledge through exploration and active learning. Hands-on materials are used instead of textbooks, and students are encouraged to think and explain their reasoning instead of memorizing and reciting facts. Education is centered on themes and concepts and the connections between them, rather than isolated information.

Instruction : Under the theory of constructivism, educators focus on making connections between facts and fostering new understanding in students. Instructors tailor their teaching strategies to student responses and encourage students to analyze, interpret, and predict information. Teachers also rely heavily on open-ended questions and promote extensive dialogue among students.

Assessment : Constructivism calls for the elimination of grades and standardized testing. Instead, assessment becomes part of the learning process so that students play a larger role in judging their own progress.

Constructivism is a way of thinking about knowing, a referent for building models of teaching, learning and curriculum (Tobin and Tippin, 1993). In this sense it is a learning philosophy and it may also become a teaching philosophy.

Some common tenets

1. Learning is a search for meaning. Therefore, learning must start with the issues around which students are actively trying to construct meaning.
2. Meaning requires understanding wholes as well as parts. And parts must be understood in the context of wholes. Therefore, the learning process focuses on primary concepts, not isolated facts.
3. In order to teach well, we must understand the mental models that students use to perceive the world and the assumptions they make to support those models.
4. The purpose of learning is for an individual to construct his or her own meaning, not just memorize the "right" answers and regurgitate someone else's meaning. Since education is inherently interdisciplinary, the only valuable way to measure learning is to make the assessment part of the learning process, ensuring it provides students with information on the quality of their learning.

Constructivism also can be used to indicate a theory of communication. When you send a message by saying something or providing information, and you have no knowledge of the receiver, then you have no idea as to what message was received, and you can not unambiguously interpret the response. Viewed in this way, teaching becomes the establishment and maintenance of a language and a means of communication between the teacher and students, as well as between students. Simply presenting material, giving out problems, and accepting answers back is not a refined enough process of communication for efficient learning. Some of the tenets of constructivism in pedagogical terms:

- Students come to class with an established world-view, formed by years of prior experience and learning.
- Even as it evolves, a student's world-view filters all experiences and affects their interpretation of observations.
- For students to change their world-view requires work.
- Students learn from each other as well as the teacher.
- Students learn better by doing.
- Allowing and creating opportunities for all to have a voice promotes the construction of new ideas.

A constructivist perspective views learners as actively engaged in making meaning, and teaching with that approach looks for what students can analyse, investigate, collaborate, share, build and generate based on what they already know, rather than what facts, skills, and processes they can parrot. To do this effectively, a teacher needs to be a learner and a researcher, to strive for greater awareness of the environments and the participants in a given teaching situation in order to continually adjust their actions to engage students in learning, using constructivism as a referent.

Constructivist learning environments

Most educational technologists that adopt some kind of constructivist stance also believes in collaborative learning (see socio-constructivism, CSCL etc.), construction and that learning is siutated (see situated learning). E.g. Jonassen and Land (2002) suggests three cornerstones for constructivist learning environments:

- Context
- Construction
- Collaboration.

This minimal set can be expanded, e.g. in Marcelo Milrad's (2002) Instructional design model for interactive learning environments (ILEs), we find the following elements and that can be enhanced with technology.

- Authentic activities: presenting authentic tasks that conceptualise rather than abstract information and provide real-world, case-based contexts, rather than pre-determined instructional sequences.
- Construction: learners should be constructing artefacts and sharing them with their community;
- Collaboration: to support collaborative construction of knowledge through social negotiation, as opposed to competition among learners for recognition;
- Reflection: fostering reflective practice;
- Situating the context: enables context and content dependent knowledge construction; and,
- Multi-modal interaction: providing multiple representations of reality, representing the natural complexity of the real world.

Many such list exist (see also the entry on socio-constructivism), but there is no clear definition of what we mean by constructivist learning environments. They certainly can be distinguished from behaviorist designs, but within distinctions may become quite subtle. As a more clearcut example we cite Hay and Barab's distinction of apprenticeship and constructionist learning environments: “In the end, we believe the differences lie in whether the learning environment has a community-centered focus or a learner-centered one. Both environments share authenticity of practices and goals, ownership of the environment by the learners, and a focus on project outcomes rather than tests. Community-centered environments focus on imparting fixed community practices, and learners are engaged in activities with well-defined goals and subgoals. The definition of success, for the learner, is becoming a community member, and the mentors are invested both in learner development and the quality of the outcome.Learner-centered environments focus on learners' developing emergent skills, where goals are ill defined, where the success is the development of a high-quality product, and where mentors are facilitators, but do not have added investment in the quality of their product.” (Hay and Barab:318).

Principles of constructivism.

There are many specific elements and principles of constructivism that shape the way the theory works and applies to students. Learn about the different principles of constructivism and how they make up the whole theory.

- Knowledge is constructed. This is the basic principle, meaning that knowledge is built upon other knowledge. Students take pieces and put them together in their own unique way, building something different than what another student will build. The student’s previous knowledge, experiences, beliefs, and insights are all important foundations for their continued learning.
- People learn to learn, as they learn. Learning involves constructing meaning and systems of meaning. For example, if a student is learning the chronology of dates for a series of historical events, at the same time they are learning the meaning of chronology. If a student is writing a paper about history, they are also learning principles of grammar and writing as well. Each thing we learn gives us a better understanding of other things in the future.
- Learning is an active process. Learning involves sensory input to construct meaning. The learner needs to do something in order to learn, it’s not a passive activity. Learners need to engage in the world so they are actively involved in their own learning and development. You can’t just sit and expect to be told things and learn, you need to engage in discussions, reading, activities, etc.
- Learning is a social activity. Learning is directly associated to our connection with other people. Our teachers, our family, or peers, and our acquaintances impact our learning. Educators are more likely to be successful as they understand that peer involvement is key in learning. Isolating learnings isn’t the best way to help students learn and grow together. Progressive education recognizes that social interaction is key to learning and they use conversation, interaction, and group applications to help students retain their knowledge.

- Learning is contextual. Students don't learn isolated facts and theories separate from the rest of our lives—we learn in ways connected to things we already know, what we believe, and more. The things we learn and the points we tend to remember are connected to the things going on around us.
- Knowledge is personal. Because constructivism is based on your own experiences and beliefs, knowledge becomes a personal affair. Each person will have their own prior knowledge and experiences to bring to the table. So the way and things people learn and gain from education will all be very different.
- Learning exists in the mind. Hands-on experiences and physical actions are necessary for learning, but those elements aren't enough. Engaging the mind is key to successful learning. Learning needs to involve activities for the minds, not just our hands. Mental experiences are needed for retaining knowledge.
- Motivation is key to learning. Students are unable to learn if they are unmotivated. Educators need to have ways to engage and motivate learners to activate their minds and help them be excited about education. Without motivation, it's difficult for learners to reach into their past experience and make connections for new learning.

Types of constructivism.

There are different types of constructivism that educators can use to find success with this learning theory.

- Cognitive. Cognitive constructivism focuses on the idea that learning should be related to the learner's stage of cognitive development. These methods work to help students in learning new information by connecting it to things they already know, enabling them to make modifications in their existing intelligence to accommodate the new information. Cognitive constructivism comes from the work of Jean Piaget and his research on cognitive development in children.
- Social. Social constructivism focuses on the collaborative nature of learning. Knowledge develops from how people interact with each other, their culture, and society at large. Students rely on others to help create their building blocks, and learning from others helps them construct their own knowledge and reality. Social constructivism comes from Lev Vygotsky, and is closely connected to cognitive constructivism with the added element of societal and peer influence.
- Radical. Radical constructivism is very different from cognitive and social constructivism. It focuses on the idea that learners and the knowledge they construct tell us nothing real, only help us function in our environment. The overall idea is that knowledge is invented, not discovered. The things we bring to the table make it impossible for us to have truth, only interpretations of knowledge. This theory was developed by Ernst von Glasersfeld in 1974.

Constructivism in education.

It's important to understand how teachers can apply constructivism inside their classroom to create a unique learning environment for students. In constructivist classrooms, the teacher has a role to create a collaborative environment where students are actively involved in their own learning. Teachers are more facilitators of learning than actual instructors. Teachers must work to understand the preexisting conceptions and understanding of students, then work to incorporate knowledge within those areas. Teachers will also need to adjust their teaching to match the learner's level of understanding.

Constructivist classrooms rely on four key areas to be successful:

- Shared knowledge between teachers and students.
- Shared authority between teachers and students.
- Teachers act as a guide or facilitator.
- Learning groups consist of small numbers of students.

Constructivist classrooms are often very different from normal classrooms in many ways. Constructivist classrooms focus on student questions and interests, they build on what students already know, they focus on interactive learning and are student-centered, teachers have a dialogue with students to help them construct their own knowledge, they root in negotiation, and students work primarily in groups.

Constructivist classrooms often have teachers who do small group work, collaborative and interactive activities, and open dialogues about what students need in order to find success.

Disadvantages of constructivist methods.

The biggest criticism of constructivist learning is its lack of structure. Some students need highly structured and organized learning environments to thrive, and constructivist learning focuses on a more laid-back method to help students engage in their own learning.

Grading is often removed from constructivist classrooms and places more value on student progress, which can lead to students falling behind and not meeting standardized grading requirements.

If you are hoping to become a teacher, a degree is crucial to getting on the right path. Additionally, it's valuable for teachers to understand different learning theories and how they impact their classroom and their students.

Q.4 What is social constructivist view of science education? Explain

Constructivism is basically a theory -- based on observation and scientific study -- about how people learn. It says that people construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences. When we encounter something new, we have to reconcile it with our previous ideas and experience, maybe changing what we believe, or maybe discarding the new information as irrelevant. In any case, we are active creators of our own knowledge. To do this, we must ask questions, explore, and assess what we know. In the classroom, the constructivist view of learning can point towards a number of different teaching practices. In the most general sense, it usually means encouraging students to use active techniques (experiments, real-world problem solving) to create more knowledge and then to reflect on and talk about what they are doing and how their understanding is changing. The teacher makes sure she understands the students' preexisting conceptions, and guides the activity to address them and then build on them. Constructivist teachers encourage students to constantly assess how the activity is helping them gain understanding. By questioning themselves and their strategies, students in the constructivist classroom ideally become "expert learners." This gives them ever-broadening tools to keep learning. With a well-planned classroom environment, the students learn HOW TO LEARN. You might look at it as a spiral. When they continuously reflect on their experiences, students find their ideas gaining in complexity and power, and they develop increasingly strong abilities to integrate new information. One of the teacher's main roles becomes to encourage this learning and reflection process. For example: Groups of students in a science class are discussing a problem in physics. Though the teacher knows the "answer" to the problem, she focuses on helping students restate their questions in useful ways. She prompts each student to reflect on and examine his or her current knowledge. When one of the students comes up with the relevant concept, the teacher seizes upon it, and indicates to the group that this might be a fruitful avenue for them to explore. They design and perform relevant experiments. Afterward, the students and teacher talk about what they have learned, and how their observations and experiments helped (or did not help) them to better understand the concept.Contrary to criticisms by some (conservative/traditional) educators, constructivism does not dismiss the active role of the teacher or the value of expert knowledge. Constructivism modifies that role, so that teachers help students to construct knowledge rather than to reproduce a series of facts. The constructivist teacher provides tools such as problem-solving and inquiry-based learning activities with which students formulate and test their ideas, draw conclusions and inferences, and pool and convey their knowledge in a collaborative learning environment. Constructivism transforms the student from a passive recipient of information to an active participant in the learning process. Always guided by the teacher, students construct their knowledge actively rather than just mechanically ingesting knowledge from the teacher or the textbook. Constructivism is also often misconstrued as a learning theory that compels students to "reinvent the wheel." In fact, constructivism taps into and triggers the student's innate curiosity about the world and how things work. Students do not reinvent the wheel but, rather, attempt to understand how it turns, how it functions. They become engaged by applying their existing knowledge and real-world experience, learning to hypothesize, testing their theories, and ultimately drawing conclusions from their findings. The best way for you to really understand what constructivism is and what it means in your classroom is by seeing examples of it at work, speaking with others about it, and trying it yourself. As you progress through each segment of this workshop, keep in mind questions or ideas to share with your colleagues. Constructivism sees learning as a dynamic and social process in which learners actively construct meaning from their experiences in connection with their prior understandings and the social setting (Driver, Asoko, Leach, Mortimer & Scott, 1994). The constructivist view of learning argues that students do not come to the science classroom empty-headed but arrive with lots of strongly formed ideas about how the natural world works. In the view of constructivists, pupils should no longer be passive recipients of knowledge supplied by teachers and teachers should no longer be purveyors of knowledge and classroom managers (Fosnot, 1996). From this perspective, learning is a process of acquiring new knowledge, which is active and complex. This is the result of an active interaction of key cognitive processes (Glynn, Yeany & Britton, 1991). It is also an active interaction between teachers and learners, and learners try to make sense of what is taught by trying to fit these with their own experience. Constructivist views also emphasize generative learning, questioning or inquiry strategies (Slavin, 1994). An emphasis on constructivism and hands-on inquiry-oriented instruction to promote children's conceptual knowledge by building on prior understanding, active engagement with the subject content, and applications to real world situations has been advocated in science lessons (Stofflett & Stoddart, 1994). And constructivist views emphasizing discovery, experimentation, and open-ended problems have been successfully applied in science (Neale & Smith, 1990). Wildy and Wallace (1995) believed that good science teachers are those who teach for deep understanding: "They use students' ideas about science to guide lessons, providing experiences to test and challenge those ideas to help students arrive at more sophisticated understanding. The classrooms of such teachers are learner-centered places where group discussion, exploration and problem solving are common place." (p.143) The term 'constructivism' encompasses a variety of theoretical positions (Geelan, 1997) and has mainly been applied to learning theories, focusing on learning as a conceptual change (Driver & Oldham, 1986) and to curriculum development and teaching, mainly in science (Osborne & Wittrock, 1985). It also provides some clear pointers towards teaching strategies that might assist students in conceptual reconstruction (Hodson & Hodson, 1998), such as:

a. identifing students' views and ideas;
b. creating opportunities for students to explore their ideas and to test their robustness in explaining phenomena, accounting for events and making prediction;
c. providing stimuli for students to develop, modify and where necessary, change their ideas and views; and,
d. supporting their attempts to re-think and reconstruct their ideas and views.

Teaching methods based on constructivist views are very useful to help students' learning. The following are practices derived from cognitive psychology that can help students understand, recall and apply essential information, concepts and skills. They are used to make lessons relevant, activate students' prior knowledge, help elaborate and organize information, and encourage questioning. Important concepts from this perspective are (Slavin, 1994, p.237-239):

a. Advanced organizers: general statements given before instruction that relate new information to existing knowledge to help students process new information by activating background knowledge, suggesting relevance, and encouraging accommodation;
b. Analogies: pointing out the similarities between things that are otherwise unlike, to help students learn new information by relating it to concepts they already have; and
c. Elaboration: the process of thinking about new material in a way that helps to connect it with existing knowledge.

To explicitly build on students' existing knowledge is one of the ways to encourage deep approaches to learning (Biggs, 1995). To achieve this, teachers should have a clear idea of what students have already known and understood so that they can engage students in activities that help them construct new meanings (von Glaserfeld, 1992). Moreover, the opportunities for pupils to talk about their ideas concerning particular concepts or issues are prominent in the learning process. Teachers who employ constructivist teaching try to help pupils to learn meaningfully. They should encourage pupils to accept the invitation to learn and to take action on what they have learnt, and to provide pupils with opportunities to explore, discover and create, as well as to propose explanations and solutions. One main purpose of using the findings of research into children's preconceptions in science is to help teachers to apply constructivist ideas about learning in the classroom (Peterman, 1991). The collaborative effort among researchers and teachers on constructivist teaching is to encourage teaching which takes account of the prior ideas and understanding of children in the development of specific concepts in science, and to stress the need to provide prospective science teachers with a model for constructivist learning situations. This lays the seeds that help prospective teachers in life-long professional growth as science educators (Anderson & Mitchener, 1994). Though Wilson (2000) suggested science educators need to look beyond the confines of cognitive psychology in developing pupils' understanding of scientific concepts, the four immediate accessible points she suggested for practicing teachers to consider in teaching concepts to pupils also rooted with constructivist teaching, these were:

1. recognizing what pupils already know;
2. teach fewer concepts;
3. improve continuity across key stages and progression of the development of concepts. Pupils are exposed to scientific concepts at a much earlier stage in their education; and,
4. acknowledge the diversity of learners.

Current teaching of science

Glynn, Yeany and Britton (1991) stated that school science curricula are commonly placed on a continuum from "textbook-centered" to "teacher-centered" and that the textbook is the vehicle that drives the teaching. The textbook is usually accompanied by a large bulk of resource materials, such as additional information, overhead transparencies, wall charts, cassette tapes, teaching kits, worksheets, exercises, suggested activities and experiments, and the activity cards. Besides this, there are also "very useful" teachers' handbooks prepared by the publishers, which prescribe precisely how a concept should be taught (So, Tang & Ng, 2000). The problem of the heavy reliance on textbooks during science lessons was addressed in the American Association for the Advancement of Science Report (1989), notingthat the present science textbooks and methods of instruction emphasized the learning of answers more than the exploration of questions, memory at the expense of critical thoughts, bits and pieces of information instead of understanding in context, recitation over argument, reading in lieu of doing. Morris (1995) in discussing the pedagogy in classrooms claimed that the major resource used by teachers and pupils in Hong Kong is the textbook. It often provides the content of the lesson and many of its learning activities. Further to this, in examining the nature of the more pupil-centered tasks used in the classrooms, such as group work, problem solving and discovery learning, Morris found that these tasks are often characterized by a high degree of teacher control and a low level of pupil involvement.

Q.5 Discuss the issues and trends in science education in Pakistan.

In the past, our scientific methods and institutions have tended to emphasize the study of individual natural processes rather than systems, analysis more than synthesis, and understanding nature more than predicting its behaviour. And in many instances, science has focussed on short-term, small-scale problems, often in monodisciplinary mode, rather than on long-term, large-scale or integrated problems. While these approaches and perspectives have built up a considerable base of knowledge and led to a vast portfolio of useful technologies, especially in the 20th century, many of the problems now facing humankind can be solved only if we approach science more holistically. Greater effort is needed to understand integrated natural systems on multiple time and space scales.

Scientific findings must also be applied at the right scales. The impact of technological interventions on individual people, communities and the environment must also be carefully considered. To do this, science needs to become more multidisciplinary and its practitioners should continue to promote cooperation and integration between the social and natural sciences. A holistic approach also demands that science draw on the contributions of the humanities (such as history and philosophy), local knowledge systems, aboriginal wisdom, and the wide variety of cultural values.

The influence of science on people's lives is growing. While recent benefits to humanity are unparalleled in the history of the human species, in some instances the impact has been harmful or the long-term effects give causes for serious concerns. A considerable measure of public mistrust of science and fear of technology exists today. In part, this stems from the belief by some individuals and communities that they will be the ones to suffer the indirect negative consequences of technical innovations introduced to benefit only a privileged minority. The power of science to bring about change places a duty on scientists to proceed with great caution both in what they do and what they say. Scientists should reflect on the social consequences of the technological applications or dissemination of partial information of their work and explain to the public and policy makers alike the degree of scientific uncertainty or incompleteness in their findings. At the same time, though, they should not hesitate to fully exploit the predictive power of science, duly qualified, to help people cope with environmental change, especially in cases of direct threats like natural disasters or water shortages.

The current trend toward privatization in many countries is influencing the focus and practice of science. While in some instances the net result may be to increase research capacity and knowledge in selected areas, there is major concern that the trend may be undermining public-sector science, especially fundamental research and efforts to solve socially important problems of no interest to commercial enterprises. Patent protection of private intellectual property, for example, makes the job of public research more difficult. There is also concern over the social implications of private ownership and control of technology, and its effect on broad public scientific literacy, and on options for public choice.

Another major trend shaping science is globalization. The end of the Cold War, growing technology demand from emerging economies, world recognition of the interconnectedness of the planet's biophysical systems and improved communications, especially via the Internet -- all these forces are boosting cross-border scientific cooperation and information exchange between individual researchers, institutions and governments. However, much of the expansion is occurring in just a handful of scientifically advanced countries. For science to be truly global, more effort is needed to ensure all countries, rich and poor, and a wide range of world cultures are included in collaborative research and technology transfer. This is especially important in areas like global climate change which will affect, sooner or later, all human beings. With the right policies in place, joint scientific work in critical areas such as the Arctic, for example, could serve as a model for other types of global cooperation.

A major challenge for global science is to find institutional arrangements conducive to success. The proliferation of international networks and programs, the so-called "acronym jungle", reflects a rather ad hoc approach, necessitated in part by the narrowness of purposes of established scientific institutions and the lack of strategic, integrated support by national governments in areas like global change or international aid. What is needed is the formation of true international partnerships that allow scientists in different disciplines and countries to fully support each other's aims and share resources and management duties to mutual advantage.

Recommendations

Scientists and scientific institutions should

- promote multidisciplinary approaches to research, encourage cooperation between the social and natural sciences, and draw lessons from the humanities, local knowledge systems and aboriginal wisdom;
- encourage a holistic approach to problem solving that takes into account a realistic range of socioeconomic conditions and effects, as well as multiple time and space scales, where appropriate;
- carefully explain the implications and the inherent limitations of their research findings to the public;
- fully exploit the predictive power of science to serve social needs with candid awareness of the limitations of scientific predictions;
- promote the inclusion of scientists from resource-poor countries in international cooperative projects and maximize their access to information and technology;
- encourage the creation of science-coordination mechanisms at the highest level of the United Nations, fully involving the governments of all countries, as a way to promote integrated responses to global problems.

Communication and Education

Within the general public, there is certain measure of mistrust and even fear of science and technology (S&T). Some is based on public experience, but much is the consequence of a significant communications gap between scientists and society. Many reasons are advanced for these attitudes: public ignorance or misunderstanding of science, inaccurate or biased media coverage, uneven distribution of the costs and benefits of science among different sub-groups in society, lack of public control over the applications of S&T, and the inability of some scientists to communicate ideas in plain language. The issue of nuclear waste disposal is one example of how the gap between scientific findings (which, in this case, suggest that safe disposal technologies exist that are at least as safe as other industrial risks accepted by society) and public opinion and behaviour (continuing opposition to the use of such technologies) may sometimes appear intractable, that is, not amenable to solution simply through improved communication or further technical research.

Good scientific communication via the mass media is especially important in those areas directly and strongly affecting people's lives — for example, before, during and after natural disasters such as storms, volcanic eruptions and earthquakes, as well as in the general area of global change or depletion of natural resources. In communicating their ideas, scientists should make clear the limitations of their predictions and other pronouncements. But they should not shy away from public pronouncements just because their messages contradict public wishes or expectations; indeed, they should be prepared for negative reactions in those instances, and carefully explain the basis for their scientific conclusions or opinions.

Apart from communication by the mass media which is largely unidirectional, communication in the sense of an ongoing dialogue between scientists, the public, and policy-makers is also important. This may take many forms: public policy consultations and review committees, science fairs, open houses, and public information services provided by universities, research institutes and private companies. As the demand for transparency and accountability in science grows, communication of this type — as well as public participation in decision making about the applications of S&T — becomes imperative. Unfortunately, resources for such dialogue are lacking not only among scientific institutions but among those groups in society who have a particular stake in scientific developments and therefore something to gain through contact with scientists. Increasing privitization of scientific activity also discourages open communication of scientific findings and uncertainties.

Science education, particularly training in multidisciplinary and team approaches to research, is also in need of reinforcement. Many science education programs still focus on individual student assignments and individual evaluation, whereas the trend in both the public and private sector is toward team work, and the needs of society are increasingly met by the concerted efforts of many areas of investigation. Science, if it is to appeal strongly to youth, also needs to be demystified by educators — that is, presented in an attractive, stimulating fashion, with the abstractions of theory strongly linked to everyday life.

Furthermore, students need to be more fully involved in public discussion of science and its applications. Not only are they the ones who will be most affected by the current direction of science, they are also the scientists and policy makers of tomorrow.

Recommendations

- To improve the quality of science journalism, the mass media should engage more journalists with scientific training. At the same time, the mass media and specialized educators should be enlisted to help train scientists or their spokespersons in the fundamentals of public communication and to familiarize them with the expectations and operating parameters of the mass media.

- The concept of scientific clearing houses — services to help journalists interpret scientific data, decipher technical language, and distinguish scientifically credible claims from unsubstantiated ones — should be promoted. UNESCO national commissions should also consider setting up scientific information services aimed at improving the quality and quantity of science stories in the media and ensuring that differing viewpoints are presented.
- Science community partnerships -- for example, between research institutes, private firms, the media, and governments — are an effective and practical way to share the costs of communicating science to the public. These should be encouraged.
- Educational authorities should encourage teamwork training and multidisciplinary approaches to science education. They should also attempt to demystify science to make it attractive to a larger proportion of students. University and private-sector experience with team-oriented research should be documented and analyzed with a view to identifying the best current practices in North America.

North-South Issues

Science in the developing world differs from that in the industrialized world in three main ways: budgets are much smaller, research agendas are different because the socioeconomic and biophysical problems to be solved are different, and there is a lower level of access to and public understanding of scientific information and technology. The North-South knowledge gap is viewed by some as the most pressing social and economic aspects of modern science.

Many developing countries have well-qualified scientists but often they are few in number and lack the resources and political support needed to solve complex problems or to apply their knowledge to national issues. In Mexico, where agriculture remains an important part of the national economy, scientific work related to food production and food security is complicated by a web of social problems such as rural poverty, social discrimination against peasants, migration to cities because of changes in land use, weak transportation and marketing services, and lack of farmer access to credit. In the area of health, too, the problems of developing countries are much different than those of developed countries. Chagas' Disease and schistosomiasis, for example, are endemic in many developing nations, yet they receive very little attention by health scientists and pharmaceutical firms in industrialized countries.

While there are number of North-South cooperative programs to support science in developing countries and improve technology transfer, much more should be done. Water management, tropical disease research, and energy-efficiency technology were identified as areas where the current co-operative programs are weak, but in which the industrialized countries can provide valuable assistance to developing countries.

In the case of international research on large-scale problems like global change, most developing countries are unable to contribute to those scientific components requiring sophisticated research facilities and technologies.

However, there are other effective but inexpensive ways for them to participate, such as regional monitoring and carrying out studies of local conditions and effects. It was suggested, for example, that Mexico could contribute to research on climate change by carrying out, at very low cost, epidemiological studies of a possible link between urban air quality and recently observed seasonal increases in cardiovascular disease and pregnancy-related hypertension. ICSU has an important role in ensuring that developing countries are involved in global change studies on imaginative but affordable and practical ways.

Another symptom of the North-South science gap is the inequitable distribution of profits generated by new technologies and products based on plant genetic resources obtained from developing countries.

Recommendations

- Efforts should be stepped up to give developing countries better access to scientific expertise, information and technology, especially in the areas of disaster relief, health, energy, and water management. In particular, the scientific and technical know-how of military organizations should be harnessed to monitor and alleviate the effects of disasters around the world.
- Measures are needed to systematically involve all countries in research on global change. Developing countries' scientific knowledge of local conditions and effects should be harnessed in the worldwide effort to understand, predict and adapt to global change and the growing understanding of changes in climate, water, and soil incorporated in international assistance programmes.
- Countries and communities should be fairly compensated for their contribution of plant genetic resources that lead to commercially profitable technologies.
- As a priority, science should address the basic needs of the sick and disadvantaged in the poorest countries.

Economics versus Sustainable Development

Science today seems caught in a cross-fire between two opposing world views. On the one hand, science is a major tool of the ideology currently driving the world economy, namely that of the free market system, continual growth and the pursuit of personal wealth. On the other hand, science is increasingly being called on to produce knowledge and technology that promote environmentally sustainable, people-oriented development and long-term management of resources.

The world economy continues to rely heavily on cheap oil, a non-renewable resource and major contributor of greenhouse gases. Fossil fuels - oil, coal, natural gas - will continue to power world industry for several decades. The fact that they will do so despite the availability of technically feasible alternative "green" energy technologies, brings the dilemma into sharp relief. Examples of the conflict between current economic forces and the need for sustainable development can be found in many other domains as well. The imposition of structural adjustment policies by international financial institutions, for example, has forced some countries to reorient agricultural research and production to focus on cash crops that generate foreign currency rather than food crops for local consumption. In some cases, such policies have put food security and the continued production of the land in jeopardy, created enormous personal hardship for citizens, and led to social unrest.

Free trade arrangements, too, may pose a threat to some of the underlying components of sustainable development, affecting biodiversity, community self-reliance, and local knowledge systems. In some cases, the elimination of trade barriers between countries has led farmers to abandon the cultivation of traditional crop varieties that were well adapted to local conditions and tastes, in favour of imported varieties that may respond better to newly expanded markets.

Deregulation and privatization are two trends aimed at improving commercial competitiveness, and stimulating economic growth. Yet in some sectors such as energy production and food it is becoming clear that these trends cannot be reconciled with the requirement imposed by sustainable development that hidden environmental and social costs of economic production — that is, costs bourne by present or future society but not normally reflected in prices of goods and services like energy, be taken into account.

In the past, developments in the energy field have had more to do with the protection of vested economic interests than with concern for the public good or environmental conservation. The prospect of that approach being perpetuated is a major concern for the future of energy science, since fossil fuels are a finite resource and a major contributor of greenhouse gases, and research or energy alternatives is handicapped.

Recommendations

- Policy makers must accept that, for certain key areas like energy development, decisions must not be based only on political expediency — such as the prospect of short-term economic benefits and job creation. To do so denigrates the role of forward-thinking research and development (R&D) and undermines long-term social development. Rather, what is needed is a vision of the world that looks "seven generations" ahead, in the manner of the holistic philosophies of North American aboriginal people.
- Public debate on the dangers of "consumptive" lifestyles typical of the industrialized countries, needs to be reactivated. If everyone on the planet lived as many North Americans do, we would need the resources of "seven Planet Earths". As this is clearly impossible, the implications of inevitable major changes soon to come should be openly discussed at all levels of society.
- Scientists need to cultivate a new vision of science — one that promotes the development of sustainable "closed" systems of production and consumption, which are compatible with the recycling behaviour and equilibrium of natural systems.
- Agencies that provide research grants should be broader in their terms of reference and more neutral and flexible so that scientists are not continually pushed to find short-term solutions when long-term ones are needed. In some countries, the allocation of research funds is controlled by small powerful groups who engage in favouritism for their own personal gain or prestige. Governments should ensure that systems for evaluating and funding project proposals are fair, objective, and transparent.

Science Policy and Ethics

Scientific advances are never, in themselves, a guarantee of social benefit. Technology has to be treated as a servant of society, not a master. Increasing commercial productivity, while at the same time necessary, unemployment and poverty is not a socially acceptable solution. Science must be fully integrated with broad societal needs, but this tenet is not yet fully accepted. One reason for public mistrust of science is that ordinary people feel they will sometimes end up being the ones to suffer the costs of technological innovation. It was suggested repeatedly at the North American meeting that the time has come to introduce an international code of ethical conduct for scientists to ensure that science is directed for the public good.

Scientists in their daily work are sometimes isolated from mainstream society, making it difficult for them to be clearly aware of public needs. Conversely, policy makers, in need of sometimes urgent advice on technical matters, sometimes urgent, may be unaware of the scientific expertise residing under their very noses. Society has much to gain by the proactive involvement of scientists in policy making.

Medical biotechnology is a leading-edge area of science in which the pace of progress is perhaps faster than society's capacity to deal with the ethical and social implications. Genetic research, while offering major benefits for disease diagnosis and treatment, also poses serious questions about the nature and sanctity of human life and the protection of human rights. The possibility that genetic technology could be commandeered by powerful groups to pursue goals in their own interests but which may be socially destructive or discriminatory is not to be considered lightly. It is an issue of particular importance to disabled persons. Greater dialogue between scientists, policy makers and the public, especially those groups disproportionately affected by technological developments, is clearly needed.

A major concern is that recent advances in health sciences will lead to the "genetification of medicine", that is, a trend toward understanding and explaining human beings and human health largely in terms of genes and their interactions. A worry here is that the role of environmental and social factors will increasingly receive insufficient attention, leading to a one-dimensional view of diseases and disabilities.

A further ethical issue for science is what has been referred to as the "commodification" of basic human needs such as food, shelter, clothing, fuel and health services. In many countries, many of these items have traditionally been supplied through non-monetary social support structures, often family-based. As cash economies and government welfare programmes increasingly treat these necessities of life simply as commodities to be bought and sold, there is a serious risk that technological innovations, stimulated by scientists working within a commercial framework, will be exploited mainly by well-to-do minorities, with little or no benefit to the poor. The potential of science to improve human social conditions in non-material ways needs much more attention.

Recommendations

- The gaining of scientific knowledge must not be assumed to lead automatically to direct commercial policy exploitation of that knowledge. Often the knowledge is of greatest benefit if it increases public understanding and awareness. Scientists cannot always control the application of their findings. However, they have a responsibility to engage in public dialogue about the implications of scientific findings and to help distinguish between socially beneficial and socially harmful applications.

- Action is needed at the international level to protect the human species from human-induced genetic alteration and to ensure that technological applications in the fields of human genetics are ethically and socially sound. Review committees at the institutional and national levels, such as those that examine and appraise research projects, can help focus attention on key ethical and safety issues. However, stronger and higher-level mechanisms for decision-making and enforcement in this area of science are also needed. UNESCO has an important role to play in this regard.
- Scientists should be more proactive in policy making. This could be done by promoting, among governments around the world, the concept of "science/policy contracts". These agreements would recognize the value of scientific advice, but also make clear that such advice is but one ingredient in decision-making and not necessarily the overriding one. Such contracts should set clear performance standards by which the inputs of scientists can be evaluated.
- The world scientific community should consider adopting an international code of ethical conduct for scientists, similar to the Hippocratic Oath taken by physicians. This code would apply a similar principle of measurability to scientific behaviour that scientists so cherish in their day-to-day pursuit of knowledge.
- (In a commentary subsequent to the workshop, one participant suggested that the Engineer's Pledge, which undoubtedly has influenced the ethical conduct of professional engineers in several countries, could also be a model for principles of conduct of science in general, adapted to express consideration for all of humankind, ecological integrity, and long-term consequences).

Integrating Issues - Science and Society

Advances in science and its resulting technologies, such as global communication, satellite images of Earth, together with the popular fascination with dinosaurs etc., have irrevocably expanded the space and time scales with which people at many levels of society now view their world. Science is largely responsible for a growing public awareness that people share the planet with all other living creatures, that the environment which supports all life is subject to change, and that human activities are presently changing this environment and threaten to change it seriously. In the past two centuries, science has been used mainly as a tool for economic expansion and military power for the wealthier segments of the human race. It is now clear that the current consumption of natural resources and increasing stresses on the regional and local environment cannot continue indefinitely without breakdown of the natural support systems that make present civilizations possible. Science, which helped to bring about this situation, now has an over-riding responsibility to help societies make a transition from an obsession with growth to achievement of a dynamically stable and sustainable ecological and economic system. In this transition, an alliance between modern technical science and the holistic wisdom from indigenous societies and philosophers from all cultures can be very important.

In the coming century, the rate of change of natural and human conditions and issues can be expected to continue to accelerate. Scientists have an increasing obligation to become involved with policy-makers and the public in finding and implementing solutions or means of adaptation to issues that are both local and world-wide, such as reconciling the present competitive profit motive with the common good; providing for contributions from and benefits to marginalized elements of society and minority cultures; justifying current expenditures to prevent costs or damages to future generations; rewarding collective rather than individual efforts. The role of science in society and governance has never been more important.