Response to the Changes to the Science Curriculum Standards
General responses

- The Board and the Commissioner have outlined a process for the development of curriculum standards for science and other subject areas. This process is not being followed. The Science Standards writing committee is broad cross section of Kansas citizens that includes experts in science, science education working with community members. In addition to the expertise and State wide representation, following the well-tested process gives validity and credibility to the work of the committee. The committee should be allowed to finish its work with the panel's **final** recommendations going to the Board, before the Board begins its standards process. At this point the committee is looking for the feedback of the external review to finish its process and providing Draft three to the State Board for consideration.

- Committee recommendations for standards do not include scientific theories on the origin of life. While the subject of life's origins is within the province of biology, the scientific community does not consider the subject as part of evolutionary theory, which assumes the existence of life and is directed to an explanation of how life evolved after it originated. The committee feels that the introduction of life's origins and the scientific explanations for the origin of life are not a fundamental part of K-12 student's education and should not be included in the K-12 Content Standards. However, evolution is a core theory of all science and should be clearly defined and included in the K-12 Content Standards.

- The language and concepts of the minority report that emerge from the writing committee in December 2004 are the changes made by the Board (7/05) and the Board subcommittee. Each of the suggestions from the minority report was discussed at length, voted on by the full committee, as a part of the writing process. The committee discussion of each of these changes with a complete response to each of the changes suggested was reported by Dr. Posny in her summary of the January 27, 2005 writing committee meeting. In each case, a two-thirds majority of the expert panel of Kansans feels these changes were not appropriate for inclusion in the State Science Standards.

- The minority report comes directly from the language of the Intelligent Design Network and Discovery Institute. Critical analysis of evolutionary theory is a repeated theme of both organization's web sites and literature. This critical analysis has no basis in science or science education. The suggested critical analysis has no scientific credibility, yet this ID inspired language is used repeatedly in the minority report and through Board Subcommittee draft.

- Critical analysis, as it is understood by the science community, is the constant and ongoing testing of scientific knowledge – all scientific knowledge. Scientific critical analysis occurs within well developed and very specific rules and guidelines. As a part of the ordinary process of science this critical analysis and the rules and guidelines are included in *Standard 1: Inquiry* and *Standard 7: History and Nature of Science*. Understanding science in this way is an important understanding for students. To single

out one particular concept or scientific explanation for special treatment is confusing and inappropriate.

- The changes to the Kansas Science Standards come directly from the language of the Intelligent Design Network and Discovery Institute. As clearly articulated by these groups, their strategy is to create an opening so that "alternative" theories to evolution can be introduced in the science classroom. They do not try to introduce Intelligent Design or creationism into public school curriculum, but just create the opening for the introduction of this philosophy. The Intelligent Design supporters are attempting to disguise this philosophy with marginally acceptable language. It is clear Intelligent Design promotes a particular religious doctrine over mainstream religious views. The Courts have held the that the First Amendment to the U.S. Constitution does not permit a state to require that teaching and learning must be tailored to the principles or prohibitions of any particular religious sect or doctrine. (*Epperson v. Arkansas* (1968) 393 U.S. 97, 37 U.S. Law Week 4017, 89 S. Ct. 266, 21 L. Ed 228) Public schools and particularly science classrooms should not be a forum for this kind of evangelism. Recognizing that curriculum proposals for "intelligent design" are equivalent to proposals for teaching "creation science. There is an important role for religion in the education of a literate society, just not in the guise of science.

- Page iii – The committee request that the dedication of the writing committee and the listing of the names of the writing committee be deleted from this document.

Incorrect statements in the changes

The following statements from the Standards are incorrect. In some cases, these statements are in direct conflict with other statements in the Standards. Statements from the Standards are italicized, followed by an indented response paragraph.

Nature of Science – page xi

> Draft two of the Committee Standards is consistent with the definition of science as recognized by AAAS, NSTA, NABT, and the National Academies of Science. This definition has been reviewed by these agencies for its meaning and content and was found to be a strong, clear statement. The language of the changes is confusing and misleading. The most important change is that the limit of science has been removed; explaining natural phenomena by natural causations. The changed nature of science seems to indicate that science is only a process and as long as individuals are doing that process, they are doing science – no matter what it is applied to. Science does not claim to have all knowledge and does not claim to be the only way of understanding. The tentative nature of all science and the limits of science as discussed clearly in the standards. This discussion is in conflict with the limits of science discussed in the standards.

Patterns of Cumulative Change: Page xiii
Although science proposes theories to explain changes, the actual causes of many changes are currently unknown (e.g. the origin of the universe, the origin of fundamental laws, the origin of life and the genetic code, and the origin of major body plans during the Cambrian explosion).

> Science does not proposes theories, people do. This sentence also confuses that meaning of theory in science. Theories are well supported scientific explanations, not the tentative idea suggested by this sentence. In addition, science does not determine "actual causes"; the societal equitant of proven knowledge, but always deals with a degree of uncertainty. This tentative aspect of scientific knowledge is clearly discussed in both Standard One and Standard Seven. The message of the sentence is in conflict with the rest of the document, functioning as a disclaimer to say that science (scientists) have ideas but really do not know anything. The science community has a good deal of information about the listed items. For example, the Cambrian explosion is only one increase in biodiversity on the planet and most of the explosion was in body from, not diversity. The origin/change of major body plans during the Cambrian explosion has been clearly linked to small changes in HOX genes. There have been dramatic increases in biodiversity after each of the five major extinctions on the planet as well, for reasons that are clearly articulated in the scientific literature. While these are active areas of scientific research, the committee determined these ideas were beyond the scope of the K-12 Science Standards.

Grades 5-7 S3B3 Teacher notes, page46 The theory of biological evolution is an explanation of how gradual changes of characteristics of organisms over many generations may have resulted in variations among populations and species..

> Evolutionary theory does not specify a rate (*gradual*). In some cases, fossils record indicates sudden bursts of increased complexity, long periods of stability. This is not at in any way at odds with evolutionary theory. Steven J. Gould, a prominent evolutionary scientist, proposed the idea of variable rates of species formation.
> A change is characteristics is not necessarily an evolutionary change and does not necessarily result in variations at the populations or species level. The sentence misidentifies where evolutionary changes occur and how hey occur. Teachers could easily follow this logic to believe that Lamarckian evolution is correct.

Multiple references to *"historical hypothesis"*.

> There is a false distinction of "historical" sciences from the nature of all science. The changes indicates that science that is historical rather than strictly empirical in nature differs from experimental disciplines like chemistry and physics because experiments cannot be used to directly test its hypotheses. Historical is not a distinction that is used in science to describe some kind of "different" science or science methodology. In looking at what could be called historical science, Geology would be a good example. Geology is science. Geology conforms to all aspects of the physical sciences. Fundamental principles in geology are an empirical approach to deciphering earth history and are based on common physical laws. Principle of superposition, Principle of original horizontality, Principle of Original, Lateral Continuity, Principle of Cross-cutting

Relationships, Principles of Components are all description of observable geologic phenomenon. Current theory in Geology ; Plate Tectonics published in 1963, required more data from two separate strands of research and years of confirmed predictions before it was commonly accepted as theory. All empirical data requires interpretation and some degree of inference, whether we are describing release of energy from electron transport, atomic structure attempting to explain gravity or the rotation of the planets around the sun. This notion of historical science is inserted into the documents and creates a conflict with Standard 1: Inquiry, Standard 7: History and Nature of Science, and the presentation of science in the Earth Science Standards at all grade levels.

Grades 8-12 S3B2In. 1 Page 76 Additional specificity
c. The order of the nucleotide sequences within the gene is not dictated by any known chemical or physical law.

The State Board of Education received a letter signed by twenty Kansas State University Biology Faculty members. Addressing this issue they said;

> One of the most problematic, confusing, and false statements is the claim that "The order of the nucleotide sequences within the gene is not dictated by any known chemical or physical law." Scientists have documented many evolutionary adaptations and the nucleotide sequences (the organization of the DNA that directs heredity) responsible for them. Small changes in sequences governed by physical and chemical laws, under the influence of biological processes, are called microevolution. Examples of such changes include, but are not limited to antibiotic resistance, adaptations to high and low temperature environments, production of specific proteins, domestic plant and animal breeding, and changes in resistance and infectivity by viral and bacterial diseases. This proposed change to the Kansas Science Standard directly contradicts microevolution, which is readily observable and widely accepted.

As the KSU professors point out, this statement is in direct conflict with the acceptance of microevolution, which is clearly stated on the same page of the Standards.

Grades 8-12 S3B3In.1 Additional specificity Page 78
a. *Biological evolution postulates an unguided natural process that has no discernable direction or goal.*

> Biological evolution does not postulate; people do. The sentence is grammatically incorrect. It also seems to state that evolution guesses that life arose from an unguided natural process. Science does not have the tools or methods to determine if natural processes are guided or unguided. Science process clearly states that teleological thinking in not a part of science, since science does not have the tools to understand designed purpose. The statement again confuses the use of the word theory in science. Evolutionary theory does not postulate, but like all scientific theory, is an explanation.

Grades 8-12 S3B3In.1 Additional specificity Page 78-79

f. The view that living things in all the major kingdoms are modified descendants of a common ancestor (described in the pattern of a branching tree) has been challenged in recent years by:

This is a difficult sentence to read however it appears to be an attempt to describe a challenge the scientific view of evolution. The branching tree is a metaphor that should not be confused with an actual description of evolution. There are not issues in the science community that challenge evolutionary theory.

i. Discrepancies in the molecular evidence (e.g. differences in relatedness inferred from sequence studies of different proteins) previously thought to support that view.

Discrepancies cannot occur in evidence, only in our interpretations of the evidence. There is nothing in the scientific literature to support this statement. The message of this statement goes again to scientific knowledge as "proven" and seems to contradict the stated progressive nature of science.

ii. *A fossil record that shows sudden bursts of increased complexity (the Cambrian Explosion), long periods of stasis and the absence of transitional forms rather than steady gradual increases in complexity, and*

Evolutionary theory does not specify a rate (sudden vs. gradual). In some cases, fossils record indicates sudden bursts of increased complexity, long periods of stability. This is not at in any way at odds with evolution. Steven J. Gould, a prominent evolutionary scientist, proposed the idea of variable rates of species formation.

Studies that show animals follow different rather than identical early stages of embryological development.

In the letter received by the State Board of Education from twenty Kansas State University Biology Faculty members, they also addressed this issues saying;

> Another incorrect proposed indicator states "Whether microevolution can be extrapolated to explain macroevolutionary changes (such as new complex organs or body plans and new biochemical systems which appear irreducibly complex) is not clear." There is extensive evidence supporting a scientific view of how complex organs and body plans evolved. All complex biochemical and organ systems are simple variants of those found in related organisms. To say that something is "irreducibly complex" means nothing to scientists, since many previously intractable events (e.g., the movement of stars and planets in the sky) were eventually explained by science. Biologists are explaining ever more biological complexity.
>
> Yet another incorrect set of indicator statements is "The view that living things in all the major kingdoms are modified descendants of a common ancestor (described in the pattern of a branching tree) has been challenged in recent years by: i. Discrepancies in the molecular evidence (e.g. differences in relatedness inferred from sequence studies of different proteins) previously thought to support that view, ii. A

fossil record that shows sudden bursts of increased complexity (the Cambrian Explosion), long periods of stasis and the absence of transitional forms rather than steady gradual increases in complexity, and iii. Studies that show animals follow different rather than identical early stages of embryological development". First, molecular evidence has solidified, not contradicted, the view of life as arising from a common ancestor. Second, stasis, bursts of complexity, and gradual change are not at odds with evolution. Steven J. Gould, a prominent evolutionary scientist, proposed the idea of variable rates of species formation but also worked tirelessly to educate the public about how evolution is sufficient to explain diversity and the fossil record. Third, developmental biology has made tremendous strides in describing embryonic development and has greatly enhanced our understanding of evolutionary relationships among species. For example, the 1995 Nobel Prize for Medicine was awarded for work on a common set of genes (including HOX genes) that influence development and body plans of creatures as diverse as sea anemones, fruit flies and humans. Small changes in these genes can result in vastly different body plans. Developmental biologists are rapidly increasing their understanding of animal development, and nothing they have found contradicts evolution.

Grades 8-12 S3B3In.3 additional specificity

d. *Whether microevolution (change within a species) can be extrapolated to explain macroevolutionary changes (such as new complex organs or body plans and new biochemical systems which appear irreducibly complex) is controversial. These kinds of macroevolutionary explanations generally are not based on direct observations and often reflect historical narratives based on inferences from indirect or circumstantial evidence.*

The definitions of microevolution and macroevolution are incorrect. Also, while these terms have been used in the past (primarily in the 1940-1950s in reference to work by Fisher and Wright) they are no longer in common usage. The terms were used at a time when our understanding of genetics was somewhat limited and more based on the work of Mendel. With more current understandings of genetic interaction and complexity, the terms lost their usefulness.
For more information on the development of evolutionary biology, Chapter Two of Douglas Futuyma's book Evolutionary Biology is "A Short History of Evolutionary Biology.

This is a direct introduction of Intelligent Design into the Standards. Irreducible complexity is a claim of intelligent design (Behe) and is not found in any scientific literature. This statement is again an incorrect usage of micro and macro evolution; terms which are not in common usage anymore. Also, direct observation is not the gold standard of science. In reality, all empirical data requires interpretation and some degree of inference, whether we are describing release of energy from electron transport, atomic

structure attempting to explain gravity or the rotation of the planets around the sun. These are all examples of phenomena that have not been directly observed.

Direct observation of phenomenon is also not the standard of how science is done for reasons involving human psychology. Studies of the human brain tells us that the brain generates information (for example to achieve visual constancy) and that humans frequently interrupt what they observe without knowing it. Gary L. Wells at Iowa State University demonstrated the issue convincingly in an experiment described in a recent Journal of Experimental Psychology. The researchers prepared a 60-second videotape purportedly showing a man on a roof dropping what appears to be a bomb down an air shaft. They showed the tape to 253 volunteers, who were then asked to pick out the bomber from six photographs. Unknown to the volunteer witnesses, a picture of the actor playing the bomber was not in the array. Nevertheless, every volunteer picked a suspect.

Grades 8-12 Standard 3 Benchmark 7 – Page 80
explains proposed scientific explanations of the origin of life as well as scientific criticisms of those explanations..

While the subject of life's origins is within the province of biology, the scientific community does not consider the subject of origins as part of evolutionary theory; which assumes the existence of life and is directed to an explanation of how life evolved after it originated. Evolution explores the origin of species, not the origin of life.

a A lack of empirical evidence for a "primordial soup" or a chemically hospitable pre-biotic atmosphere;
b. The lack of adequate natural explanations for the genetic code, the sequences of genetic information necessary to specify life, the biochemical machinery needed to translate genetic information into functional biosystems, and the formation of proto-cells; and

In the letter received by the State Board of Education from twenty Kansas State University Biology Faculty members, they also addressed this issue saying;

Increasing evidence on formation of organic compounds that are the building blocks of life under conditions found on early earth is accumulating in the most rigorous international scientific journals. Scientific (testable) explanations are available for the genetic code, the sequences of information (see discussion above) and the biochemical machinery needed to translate genetic information. These explanations help us to combat serious human diseases and increase agricultural productivity. The explosion of new molecular information on entire genomes of widely divergent organisms (particularly the human genome project) in no way contradicts evolution, nor does it support an alternative explanation for the origin of diversity such as intelligent design.

The sentence in b. above is trying to make the case that the lack of natural explanations lends support to alternatives to natural explanations. The notion that a lack of evidence creates a case of an alternative is clearly not scientific process, even if there were a lack ofevidence.

c. The sudden rather than gradual emergence of organisms near the time that the Earth first became habitable.

A statement of rate, sudden vs. gradual, is not supportable by current understandings. Current scientific understandings indicate that life probably developed multiple times, not just once, in this early environment. The use of the term habitable is also very vague. Deep sea worms being studied today live next to volcanic vents finding high temperature, high pressure, and very acidic environments habitable. In fact they appear to thrive. The early environment of the earth is still a very active area of scientific research.

Response to specific changes

Changes in the Introduction

Rationale Section – The rationale for curriculum standards is clearly spelled out in Board Policy. This rationale section does not occur in other curriculum standards and is an exception to the standard format for all content area standards. This is not a rationale for the Standards document but only a rationale for the changes made by the State Board of Education.

Much of the information in the Rationale section is about science, the nature of science, and evolution. Most of this information in this section is erroneous however, if included, it should be in a more appropriate section. It is not clear why Intelligent Design included in the rationale when it is not discussed or introduced in the Standards.

The rationale indicates a specific instructional strategy for teachers indicating that they should explain areas that we do not understand. It is not clear how or why a teacher might explain what we do not understand and it would seem that with precious little time in the curriculum for science instruction teachers should concentrate on helping student develop a foundation of knowledge and skills of inquiry, so that they can be life long learners?

Mission Statement – page v

*Kansas science education contributes to the preparation of **all** students as lifelong learners who can use science to make informed and reasoned decisions that contribute to their local, state, national and international communities.*

Adding the word informed does not improve the language of the mission statement. The addition adds vagueness to the credibility of information: Informed about what? The Standards are the information (an outline to content) with which students should be informed. The word also opens the door for information other then scientific information including misinformation and pseudoscience. as these are also “information”.

Nature of Science

Draft two of the Committee Standards is consistent with the definition of science as proposed by AAAS, NSTA, NABT, and the National Academies of Science. This has been reviewed by these agencies for its content and was found to be a strong, clear statement. The language of the changes is confusing and misleading. The changed nature of science seems to indicate that science is only a process and as long as we are

doing that process, we are doing science – no matter what it is applied to. The limit to science, natural phenomena by natural causations, has been removed. This is incorrect. While science is a specific process, it has limits. Science does not claim to have all knowledge and does not claim to be the only way of understanding. The tentative nature of all science and the limits of science as discussed clearly in the standards. This discussion is on conflict with the limits of science discussed in the standards.

Unifying Concepts – Patterns of Accumulated Change

The discussion above address the lack of scientific validity of this statement. The language of this change comes from the minority reported, which the writing committee discussed at the January 27th Committee Meeting.
A motion was made and seconded to add to the introduction the following language:

Although science proposes theories to explain changes, the actual causes of many changes are currently unknown (e.g. the origin of the universe, the origin of fundamental laws, the origin of life and the genetic code, the origin of major body plans during the Cambrian explosion).

A committee member shared that a lot is known about the origins of life and the universe and we continuously seek explanations. That is part of science. It cannot be stated frequently enough that everything is not known. Others felt that this is redundant and that it singles out or draw attention to specific areas of science. It was also mentioned that it was unnecessary as good science explains it anyway. Others say that students know this and it is not necessary to point it out. The interpretation as to what science does and does not know or if science is capable of knowing it just because we don't know it right now, is a concern. Intelligent design is trying to point out that because we don't know it, it can't be taught. It was emphasized by another committee member that standards are what students should know and be able to do. The interface is content versus instruction; not instructional standards. However, it was also mentioned that national standards do include instructional standards as well as assessment standards. The motion failed with 8 in favor and 15 opposed.

The changes also include equivocations of language to weaken the understandings of science to "seeks to explain".

Changes in the Grade Level Standards.

Incorrect statement s about science have been discussed. Additional reactions to the changes occur below.

Grade 5-7 Standard 3 Benchmark 5 Teacher's Notes

As they investigate different types of organisms, teachers guide students toward thinking about similarities and differences.

The meaning and intent of these sentences has been changed, suggesting a different instructional approach.

Grade 8-12 Standard 1 Benchmark 6

The issue of historical hypotheses is addressed above. This sequence of steps in these Benchmarks misrepresents the nature and process of science and is in conflict with the standard's discussion of scientific process.

Grade 8-12 Standard 3 Benchmark 2– random nucleotide sequence.

Addressed above, this statement is incorrect.

Grade 8-12 Standard 3 Benchmark 3

Benchmark 3 *major concepts of the theory of*

a. *Biological evolution postulates an unguided natural process that has no discernable direction or goal.*

However, in many cases the fossil record is not consistent with gradual, unbroken sequences postulated by biological evolution.

and differences among fossils and living organisms.

f. The view that living things in all the major kingdoms are modified descendants of a common ancestor (described in the pattern of a branching tree) has been challenged in recent years by:

b. *Discrepancies in the molecular evidence (e.g. differences in relatedness inferred from sequence studies of different proteins) previously thought to support that view.*
c. *A fossil record that shows sudden bursts of increased complexity (the Cambrian Explosion), long periods of stasis and the absence of abundant transitional forms rather than steady gradual increases in complexity, and*
d. *Studies that show animals follow different rather than identical early stages of embryological development.*

New heritable traits may result from new combinations of genes and from random mutations or changes in the reproductive cells. Except in very rare cases, mutations that may be inherited are neutral, deleterious or fatal.

d. Whether microevolution (change within a species) can be extrapolated to explain macroevolutionary changes (such as new complex organs or body plans and new biochemical systems which appear irreducibly complex) is controversial. These kinds of macroevolutionary explanations generally are not based on direct observations and often reflect historical narratives based on inferences from indirect or circumstantial evidence.

e. . However, reverse engineering and end-directed thinking are used to understand the function of bio-systems and information.

*7. explains proposed scientific explanations of the origin of life as well as scientific criticisms of those explanations. . **S**ome of the scientific criticisms include:*

a A lack of empirical evidence for a "primordial soup" or a chemically hospitable pre-biotic atmosphere;

b. The lack of adequate natural explanations for the genetic code, the sequences of genetic information necessary to specify life, the biochemical machinery needed to translate genetic information into functional biosystems, and the formation of proto-cells; and

c. The sudden rather than gradual emergence of organisms near the time that the Earth first became habitable.

The previous discussion detailed the lack of scientific credibility of all of these statements. The additions suggest additional critical analysis of particular area of science however critical analysis is a part of all ongoing science. This idea is included in Standard 1 – Inquiry and Standard 7 – History and Nature of Science. To single out one particular concept or scientific explanation for special treatment is inappropriate and misleading.

The committee feels that discussions of scientific explanations of the origin of life should be left to local level curriculum development and should not be specified in the Standards.

Grade 8-12 Standard 7 Benchmark 1

Science is used by researchers to develop new medicines and by parents to promote the health of their families.

Listed under additional specificity, these changes are confusing. The first sentence seems to discuss applied science and how the understanding of the natural world gained by science is applied by medicine. The application of science goes way beyond medicine. Parents do not use science to promote the health of their families. The may use the understandings of science to promote family health but they do not experiment on their children.

Scientific knowledge is made public through presentations at professional meetings, articles in scientific journals and other peer reviewed literature.

Scientific knowledge is not made public in other peer reviewed literature. When researchers have tried to go around the normal process of publication, they miss the critical review that is so important to science – for example, cold fusion research coming out of Utah.

Decisions the culture makes about bioethics and the use and extraction of natural resources are significantly impacted by scientific knowledge.

This statement is true however the decisions about culture are not made by scientists.

Grade 8-12 Standard 7 Benchmark 2

Science that is truly open-ended, and that allows evidence rather than preconceptions to guide explanation is the strongest and allows for constant refining and improvement of its explanations.

The Benchmark indicates that scientific knowledge is tentative and subject to evidence based changed, followed by this statement which indicates that not all science is truly open-ended and that it is driven by preconceptions. The statements are contradictory and confusing.

Grade 8-12 Standard 7 Benchmark 3

Modern science has been a successful enterprise that contributes to dramatic improvements in the human condition. Science has led to significant improvements in physical health and economic growth; however, modern science can sometimes be abused by scientists and policymakers, leading to significant negative consequences for society and violations of human dignity (e.g., the eugenics movement in America and Germany; the Tuskegee syphilis experiments; and scientific justifications of eugenics and racism).

This statement is a very odd statement to include in science standards. It seems the message to students is that "Science is great, but do not trust it." Science abuse by policy makers generally different then abuse of science by scientists. This is a complex area of the social sciences that is important but does not help students understand the Standard - *The student will develop understanding of science as a human endeavor, the nature of scientific knowledge, and historical perspectives*. Providing examples of abuse from the 1940s is misleading and will not help student develop understanding. These abuses have were fringe, horrific events that have informed the science community, who has reacted appropriately to prevent this kind of abuse from happening again. The science community has no control over policy makers and how society might use or abuse scientific understandings.

Bibliography - The Board Subcommittee draft is not consistent with sources cited.

Writing Clarity

The following examples illustrate the difficulty of changing bits and pieces of language without considering the meaning and intent of the full document. It is not clear what these sentences say, or mean.

The general idea is that the present arises from materials and forms of the past. An example of cumulative change is the formation of galaxies, explained by cosmological theories involving (among other theories) gravitation and the behavior of gasses, and the present diversity of living organisms, which the biological theory of evolution, or descent with modification of organisms from common ancestors, seeks to explain. .

explains proposed *scientific explanations of the origin of life as well as scientific criticisms of those explanations..*

However, reverse engineering and end-directed thinking are used to understand the function of bio-systems and information.

In addition, it progresses by critical analysis of: 1) properly collected data; and 2) existing theories and hypotheses, which can lead to major new scientific advances (e.g., relativity, plate tectonics, quantum theory, biological evolution).