

# **Humanising Epistemic and Pedagogic Discourses in Science Education**

## **SUMMARY OF THESIS**

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## SUMMARY

### Background of the Study

Science a word which brings along with it hope of progress, advancements, new discoveries, and revolution that affects the social-cultural setting of a human being. Science and scientific knowledge is highly esteemed and trustworthy. The genesis of science tells that it has its germination in ‘Philosophy’; from classical times until the modern era philosophy was roughly divided into two parts namely, Natural philosophy and Moral philosophy. As believed, it was way back in 1800 when the term Natural philosophy metamorphosed into a new avatar that is known as Natural Science (Feyerabend, 2005). Natural Science gradually evolves and gets specialized in a different form which includes the physical sciences and the biological sciences. Philosophy plays a most important role by focusing on the most pertinent questions related to human existence, his life and way of thinking. the main aim of philosophy is always been human welfare and since science has its string attached to philosophy it has originated with the aim of “human welfare” as its major aim. The nature of science, its epistemology are two very important elements of science and scientific knowledge. Epistemology is a branch of philosophy by which we mean “the study of knowledge” and “what it means to know something”. It deals with Epistemic Belief and addresses the most thoughtful and pertinent questions such as: What is the nature of knowledge? What are its sources? How it is acquired? What is its structure? What are its limitations? The epistemology of science plays a very important role in the development of the epistemic belief of an individual and these two together are most pertinent elements towards the construction of a valid scientific knowledge. As far as Epistemic Discourse of Science education is concerned it has not been linear development because from time-to-time different philosophers of science has revolutionised it whether it was Karl Popper’s principal of “Falsification”, Thomas Kuhn’s sensational work on “The structure of revolution”, Imre Lakatos “Proofs and Refutations”, Paul Feyerabend’s “Anarchistic theory of science” or Larry Laudan’s “Problem solving effectiveness”. The epistemic belief has evolved time to time and are still in the process of evolution. Science with its true nature, and its epistemology can be transmitted to society through science education with help of different pedagogies of science. Hence, the knowledge of pedagogical discourses of

science is equally important. In the present scenario, it has been seen that science education majorly focuses on science professional aims and has been robbed of its humanistic goals. Therefore, to channelise science education to both of its aims professional and humanistic there is need to revisit science education from the lens of Philosophy of humanism. The philosophy of Humanism is a philosophical and ethical stance that emphasizes the value and agency of human beings individually and collectively. It generally prefers critical thinking and rational evidence over acceptance of dogma or superstition. Humanism is a commitment to the perspective, interests, and centrality of the human, his belief in reason and autonomy as foundational aspects of human existence. The genesis of humanism as mentioned before from early 19th century starts right when Niethammer coined the term Humanismus to describe the neo classical curriculum he planned to offer in German secondary schools, and by 1836 the word "humanism" had been absorbed into the English language. The meaning of the term humanism has fluctuated according to the successive intellectual movements which have indented with it. It is the philosophy of humanism that should be given credit for a rebirth of a lost human spirit and wisdom. In the course of striving to recover it, however, the Humanists assisted in the consolidation of a new spiritual and intellectual outlook and in the development of a new body of knowledge. The motive of Humanism was to help men break free from the mental structures imposed by religious orthodoxy, to inspire free inquiry and criticism, and to inspire new confidence in the possibilities of human thought and creations. The philosophy of humanism has travelled a lot and has stretched its roots across the globe. Though, the philosophy of humanism and science seems very different to each other in first outlook but they share a strong relationship with each other. The most important aspect that they share in common is their aim towards human welfare and along with it there are other aspects such as their trust towards scientific method to reach to the valid knowledge, their rational approach, the four main pillars which are logic, reasoning, argumentation and aesthetics on which universe of human thinking is developed according to philosophy of humanism and these pillars holds an important place in science as well. There are many other dimensions on which philosophy of humanism and science complement each other and with this relationship they grow individually, collectively and above all with them grows science education. In the present study an attempt is made to Humanise Science Education by focussing on the two most important components of science education i.e., its

Epistemology and Pedagogy by reframing it with the help of the ‘Philosophy of Humanism’. The study aims to contextualize and refresh the perspective of Science Education through different perspectives according to which science education should be taught with the broader aim to reshape science education from the perspective of Humanism. The different aspects of the philosophy of humanism are used to reshape science education by blending humanistic elements in the teaching of science so that man and his welfare are considered the goal of science education.

### **Objectives of the Study**

1. To discern the developmental trajectory of the philosophy of Humanism.

Research Questions:

- 1.1 What is the meaning of the philosophy of Humanism?
- 1.2 How the theory of humanism has shaped the universe of human thinking?

2. To ascertain the relationship between the philosophy of Humanism and Science in general and Science Education in particular.

Research Questions:

- 2.1 On what basis philosophy of humanism does show reliance with science?
- 2.2 How to humanise science education from the perspective of the philosophy of humanism?

3. To dissertate the journey of epistemic and pedagogic discourses in science education.

Research Questions:

- 3.1 How do the models of the practice of science by prominent philosophers of science contribute to the reshaping of epistemic discourses in science education?
- 3.2 What is the voyage of pedagogical discourses in science education?
- 3.3 What is the relationship between a teacher’s epistemic belief of science and his pedagogical practices in science teaching?

4. To explicate the concept of Humanistic Aesthetics in Science.

### **Research Questions:**

- 4.1 Does Aesthetic play role in science?
- 4.2 How can educators offer opportunities for students to have Aesthetic experiences in the classroom?
- 4.3 How does Aesthetics in a scientific idea play a role in the development of scientific thinking?

### **Terms Defined**

#### **Humanism**

Humanism is a philosophy that can be defined as a commitment to the perspective, interests and centrality of a human being; a belief in reason and autonomy as foundational aspects of human existence; a belief that reason, skepticism and the scientific method are the only appropriate instruments for discovering truth and structuring the human community; a belief that the foundations for decision making are based on logic and reasoning. The implementation of the philosophy and shaping of an individual's thought process according to it is known as "Humanising".

#### **Science**

Science can be defined as a discipline through which problems and questions dealing with natural phenomena can be identified and defined, and solutions are proposed and tested. In this process, data are collected and analysed, and available knowledge is applied to explain the results. As a discipline, it has its epistemology, nature and pedagogy. It's the knowledge gained based on scientific ideas and principles which aims to make a creative and rational individual whose construction of ideas can help to better understand their surroundings, to apply the knowledge gained to bring needful changes in society and to have a direct bearing on the quality of life and individual benefit.

#### **Science Education**

Science Education deals with the education of science. The main aim of science education is the construction of scientific knowledge. It is science education that brings students close to science as a discipline and motivates them to choose science in future studies.

### **Epistemic Discourses**

Epistemic Discourses cover the journey of “Epistemology” of a particular subject which deals with different dimensions related to the nature of knowledge and the trajectory it has followed over course of time. It deals with the belief of a person here the philosophers of science related to origin, acquisition and above all construction of knowledge.

### **Pedagogic Discourses**

Pedagogic Discourses cover the journey of “Pedagogy” of a particular subject dealing with the way of teaching. It covers the changes that took place in science which have influenced its pedagogy. The epistemology, and nature of that particular subject can be imparted to the students through different pedagogies.

### **Delimitation of the study**

1. The present study does not claim to be an exhaustive exploration of the subject of science which covers all the epistemic discourses till today, rather it is a systematic assembling and critical analysis of epistemic discourses of the most prominent philosophers of science that have revolutionised science and its nature. The study is delimited to exploring epistemic discourses of four main philosophers of science namely Karl Popper, Thomas Kuhn, Imre Lakatos, Paul Feyerabend, and Larry Laudan’s and their contributions to science.
2. The present study is delimited to those pedagogies of science that are new and relevant in today’s science education.

### **Summary and Research Gaps**

The above-mentioned research studies and research articles can be bifurcated into four main headings which are the Philosophy of Humanism, the philosophy of science with special reference to the epistemology of science and pedagogy of science, science education and aesthetics in science. The research papers on the Philosophy of humanism majorly addressed different types of humanism, its genesis and background. The research papers which are focussed on Humanistic science education mainly address the importance to imbibe humanistic elements in science education, and the history and

failure of traditional science curricula. The research papers on the philosophy of science address the epistemology of five prominent philosophers of science namely Karl Popper, Thomas Kuhn, Imre Lakatos, Paul Feyerabend and Larry Laudan. The research papers on science education focus on nature, epistemology and pedagogy of science and the research papers on Aesthetics focus on aesthetics in science, meaning and theory of beauty and aesthetics in science education. The major research gaps from the entire review of the related literature convey that firstly, the included research papers address one dimension at a time whether humanism, philosophy of science, science education or aesthetics in science. Further, most of the studies are done in context with countries outside India. In addition to this none of the study is focussing on Humanism and its different aspects along with science education at the same time. Lastly, the different angles this study is planned to explore have not been explored in any other previous study that is conducted in India. The present study will explore the relationship between two: Humanism and Science with the motive to see how both humanism and science enrich each other individually and collectively. The present study will also focus on epistemic and pedagogic discourses in science by including the epistemic journey of five prominent philosophers of science, the pedagogical journey of science and how both epistemology and pedagogy influence each other. The study will also look at the essence of Humanistic Aesthetics in science. The studies mentioned are all done outside India in a completely different culture. In the present study, the researcher will unwrap different aspects and will present them in a way that these unwrapped elements will together enrich science education. In the light of the above discussion, the present study is on “Humanising Epistemic and Pedagogic Discourses in Science Education”.

### **Research Design and Methodological Approach**

The nature of the overall study is qualitative and the type of qualitative research used in the present study is Philosophical research. The type of philosophical research used in the study is “Analysis method”.

### **Tools for data collection**

The tools used for the present philosophical study are:

- The very first tool in philosophical research is the “Mind” of the researcher.

- Literature available in the forms of books, research papers, research articles, essays, poems and study-related webpages such as the British Humanist Association, American Humanist Association, Stanford Encyclopedia of Philosophy, Homi Bhabha Centre for Science Education and also went through other available literature on the internet.
- Two Open-ended Interview schedules for the science teachers teaching in classes 6<sup>th</sup> to 12<sup>th</sup> were constructed to answer RQ (2.2) and RQ (3.3). Tools are attached in Appendix I and Appendix II respectively.

### **Data Analysis and Interpretation**

- The researcher went through the content of the available literature in the form of books, research papers, journals, blogs, and different web pages. For two research questions, open-ended interviews were also conducted and notes were taken.
- After going through the content and notes of the interview, both were converted into transcripts and further analysis was done.
- For analysis, initially, themes or categories were constructed and named.
- From the constructed themes coding was done and lastly through ‘synthesis’ all the available thoughts and ideas were placed objective wise to conclude.

### **Findings**

**Objective 1:** To discern the developmental trajectory of the philosophy of Humanism. The objective intended to explore two research questions: What is the meaning of the philosophy of Humanism? What is the theory of humanism that has shaped the universe of human thinking? These two research questions were answered to achieve the first objective.

The main findings are:

- The meaning of the Philosophy of humanism is broad where broadness and openness are the essence of the Philosophy of Humanism. The distinct feature of PoH is carrying broadens with the uniqueness of its features. Its meaning could be boiled down to one thing and that is the “Welfare of human beings”. There are different aspects which help Humanism to work as per its meaning. These are as follows: “Human thinking”, “Science and scientific method”, “Self-decision making”, “Living life to the fullest”,

“Liberty of thoughts”. The PoH stands on the above-mentioned aspects and all these aspects share a very intimate relationship with it but PoH does give ‘Freedom’ to individuals on how to use these aspects in their lives which is again a very spirit of Humanism.

- The Philosophy of Humanism is a school of thought which has travelled across the globe touching every tradition and culture right from “Lokayak” an Indian school of thought to the Chinese “Silver rule” to ancient Greek and many other civilizations. It has different forms and approaches. Through the journey, it has travelled as discussed above and its different approaches one can infer about PoH that it is not just a school of thought according to which an individual must think or idealise his thought process but in itself, it is a way to live life. Its principles and characteristics do not only confined to how an individual must think but how an individual must live his life and that’s why we can say it’s a blend of both Western Philosophies such as Naturalism, Pragmatism, Realism or Idealism as they focus on the thought process of an individual and Indian Philosophy such as Samkhya, Vaisheshika, Yoga, Mimamsa or Vedanta as they are not just a way of thinking but a way an individual must lead his life.

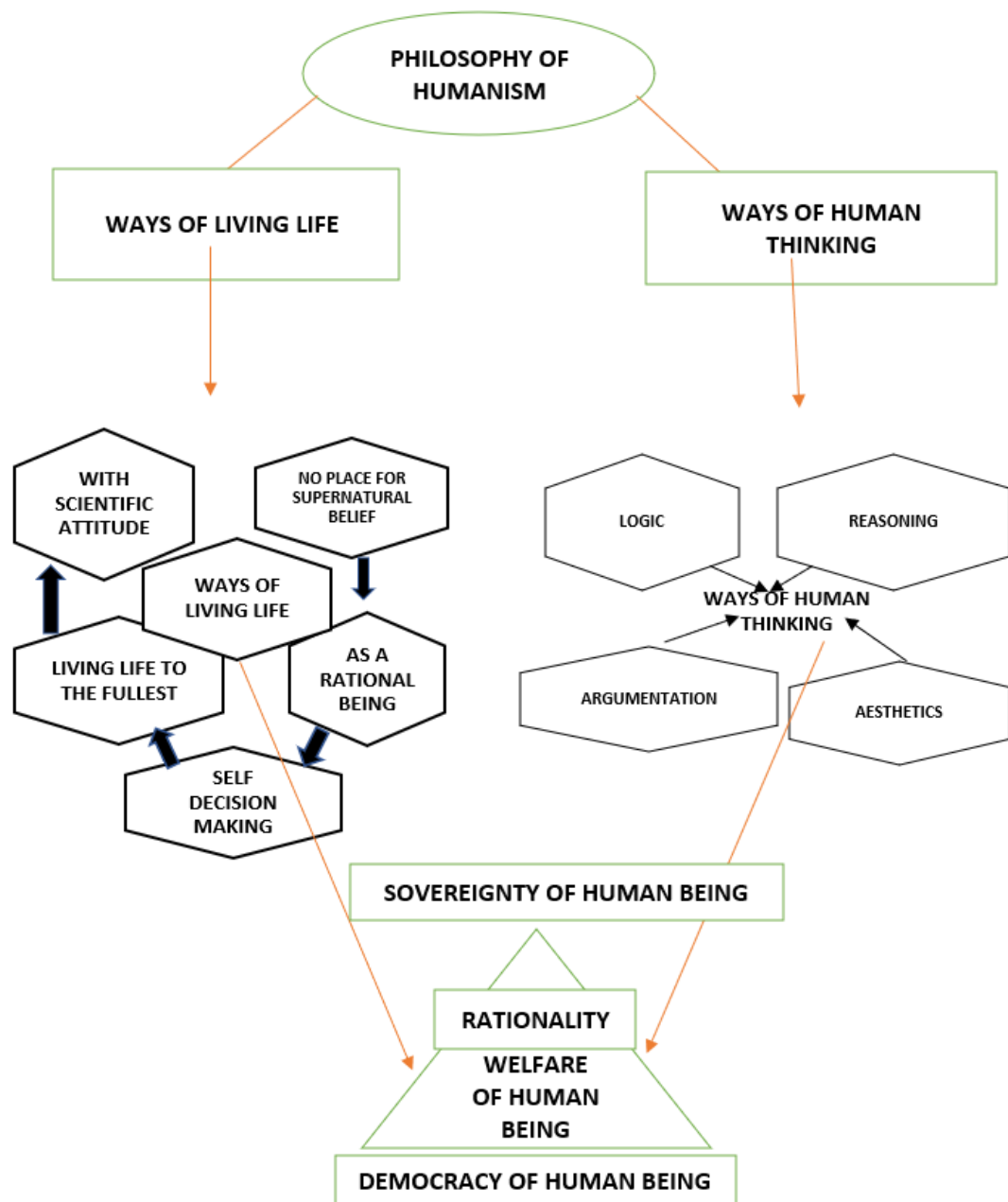
- The actions of PoH and human thinking depend on the thought process. Therefore, for an individual to follow a humanist life must first work on his thinking. The human thinking shaped by humanism has its very foundation in common with science. The study drew out four such pillars on which human thinking could be shaped as per Humanism. These pillars are:

- Logic
- Reasoning
- Argumentation
- Aesthetics

The base of human thinking is known as logic which works backstage and plays a role of the backbone of human thinking, the other is reasoning which works with logic and it is the formal statement. It is the result of logic that after critical thinking one reaches a reason which could be stated and stands as the strongest pillar for any decision a human mind makes. After this comes, “Argumentation” as discussed which validates the logic

and the reasoning. It is a must for human thinking in general and scientific thinking. It acts as a mechanism through which logic and reason must pass successfully to be accepted. The last is aesthetics, aesthetic is an essential part of human thinking as it is the aesthetics that draw attention towards nature and compels us to think about it.

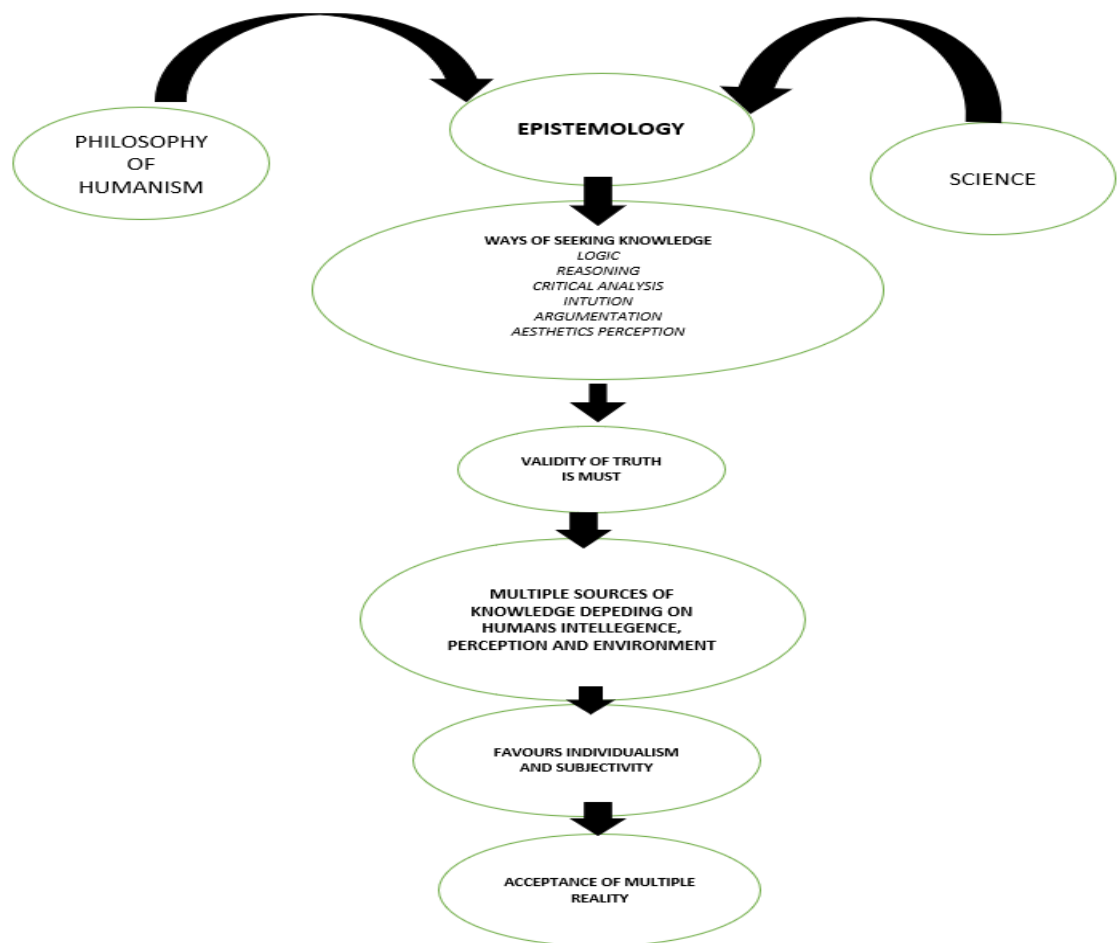
- The PoH is concerned with the welfare of human beings and the way towards the welfare of human beings is to have a humanistic scientific attitude which aims to live life to the fullest as a rational being. The dimensions of the welfare of human being according to PoH are Democracy at its base, rationality at its centre and sovereignty of man as its apex. Therefore, a humanist according to the philosophy of humanism is a being who is rational as well as enjoys the ride of life to the fullest. The concept of the philosophy of humanism is depicted below:



**Objective 2:** To ascertain the relationship between the philosophy of Humanism and Science in general and Science Education in particular. The objective intended to explore two research questions: On what basis philosophy of humanism does show reliance with science? How to humanise science education from the perspective of the philosophy of humanism? These two research questions were answered to achieve the second objective.

The main findings are:

- PoH shows reliance with science in the following aspects:
  - Rejection of Dualism and Idealism
  - Acceptance of individuality and distinctiveness
  - Naturalism
  - Ways of seeking knowledge
  - Rationalism
  - Scientific Method
  - Disbelief in religious and supernatural dogmas
  - The four main pillars of human thinking
  - Main aim towards 'human welfare
  - Humanist Metaphysics
- The epistemology of PoH and Science is quite similar. Different dimensions of epistemology that are common in both are depicted below:



The most obvious reason for the traditional science curriculum to failure was its inefficiency to keep both the aims of science education together i.e., professional, and humanistic aim. According to the literature studied and interviews transcript, to fulfil both the motives humanistic as well as scientific there is a need to bring changes in the following aspects:

- Firstly, the change in subject culture, by subject culture means a culture that is related to a discipline. It is constructed by distinct features of that subject considering its very nature, philosophy, and history along with the teacher's involvement, curriculum decisions and instructional behaviour (Aikenhead, 2003). It has been seen that the culture of science has turned to be more mechanical than humanistic where discussions, different opinions, and subjectivity have been neglected. 'Science' has been regarded as a subject with "less margin for errors" (Osborne & Collins, 2001).

- “Knowledge of the Philosophy of science” (PoS) and “History of Science” (HoS) is a must. The science teachers, curriculum developers, and textbook developers all need to know the actual nature of science which is only possible with the knowledge of PoS and HoS. It has been seen that the physics teacher regards the physics content as a collection of truth and facts about nature (Osborne et al. 2003; Aikenhead, 2003). Therefore, they completely neglect that physics content is a matter of discussion among their students while teaching. This not only questions the epistemological belief of a science teacher regarding the nature of scientific knowledge, but its impact is also seen in pedagogical practices and influences the belief of the students as well. Due to this wrong or incomplete epistemological belief of science educators about scientific knowledge, their pedagogical practices include memorization of scientific facts, audio, and video recording to learn the information, giving no scope for discussion or questioning among students. The information revealed from several related kind of literature from across the globe has highlighted that science teacher themselves have wrong or incomplete epistemological beliefs regarding science and its concepts. As a suggestion, science educators must be part of more refresher courses that revive their epistemic belief from the perspective of humanism in science. There must be in service seminars and workshops that help them to be skilled in new pedagogies that will help them to reflect humanistic perspectives in their pedagogical practices.
- Humanistic pedagogical practices that are discussed above not only aim to fulfil the humanistic goals of science but will also fulfil its professional goals. These practices will involve students in the creation of scientific knowledge and will help them to create their own epistemic beliefs about science. This kind of learning will not only increase their scientific knowledge but will enhance their creativity and curiosity about science. Both ‘creativity’ and ‘curiosity’ are two main tenets of science and science education that must be enhanced and illuminated through it. The humanistic practices for the construction of scientific knowledge involve both a few pedagogies and a few other practices that will help to achieve both the aims of science are mentioned below:
  - Inclusion of History of science
  - Constructivism as a pedagogy

- Storytelling as a pedagogy
- Project-based learning as a pedagogy
- STEAM as a pedagogy
- Argumentation as a pedagogy
- Field trips and educational tours
- Collaboration between main stakeholders as a practice

**Objective 3:** To dissertate the journey of epistemic and pedagogic discourses in science education. The objective intended to explore three research questions: How do the models of the practice of science by prominent philosophers of science contribute to the reshaping of epistemic discourses in science education? What is the voyage of pedagogical discourses in science education? What is the relationship between a teacher's epistemic belief in science and his pedagogical practices in science teaching? These three research questions were answered to achieve the third objective. The main findings of the first research question "How do the different models of the practice of science contribute to reshaping epistemic discourses in science education?" are:

1) The epistemic models and their given account of science are as follows:

***Popperian Epistemology of Science:***

Scientific knowledge must be demarcated from non-scientific knowledge on basis of refutations, not confirmations. Therefore, falsifiers of any scientific theory must deserve their due importance and even the failures in the path of scientific progress must be discussed in science education today.

- In the construction of scientific knowledge, the philosophy of science does play an important role and hence must be given a place in science education as well.
- The scientific knowledge and theories are testable, and the evaluation depends on the degree of testability. Therefore, testing all knowledge is a must before accepting it.
- Scientific knowledge is built on logic and rationality and therefore both aspects must be enhanced while teaching and learning in science.

- Popperian theory of falsification stresses falsification rather than confirmation of claims and the most reliable scientific knowledge is the one which stands firm against all confrontations.
- Popperian account of science is normative in nature that focuses on what should the scientist do and gives a framework on how scientists should work in the construction of scientific knowledge.

***Popperian Methodology of Science:***

- Logical analysis is the initial step toward reaching scientific knowledge.
- Critically testing theories and selecting them as per the result of tests goes through testing a theory against experience through the deduction of predictions.
- Critical rationalism is the core of the Popperian methodology.

***Kuhnian Epistemology of Science:***

- In the construction of scientific knowledge, the history of science does play an important role. Therefore, it must hold an important place in science education as well.
- According to Kuhnian epistemology, the progress of science and its knowledge takes place as per a “paradigm” which has its set rules and path. Hence, for him, science has a particular systematic path to be travelled on.
- There is a specific structure and pattern according to which scientific knowledge is constructed and the pattern is cyclic in nature as per Kuhnian thought.
- Kuhnian account of science is descriptive in nature and focuses on what scientists do in the process of construction of scientific knowledge instead of what they should do. Kuhnian Methodology of Science.
- The progress of science follows a pattern under a paradigm. Pre-Science->Normal Science->Crisis-> Revolution-> New normal Science-> New Crisis.
- There is a regressive competition going on between different paradigms and the one which stands out against its other rival paradigm is accepted for a time being.
- Science is a puzzle-solving activity therefore the spirit of challenge and motivation should always be infused into it. Lakatos’s Epistemology of Science

- Imre Lakatos reconcile Popperian and Kuhnian account of science as it blends both philosophy and history of science in the construction of scientific knowledge.
- According to him, the fundamental unit of assessment should be a research tradition such as Newtonian mechanics, instead of a single hypothesis or conjecture.
- Lakatos's account of science gives a Revolutionary model LMSRP – Lakatos methodological scientific research programme.
- It comprises of Hard core -> Heuristic -> Progressive/degenerative research programme • The Programs are progressive in nature when they focused on protecting the core from refutation. Lakatos's Methodology of Science
- There is a systematic way according to which science progress.
- The motive is to protect the hard core of a science research programme by using ad-hoc postulates in it.
- The methodology claimed to be a sophisticated falsificationist version of Popper's program that offered a response to what Lakatos saw as Kuhn's irrationalist view of scientific change. There is continuity in process of construction of knowledge and Scientific progress. It is a matter of repeated conjectures and refutations, new conjectures and refutations and so on.

### ***Feyerabend's Epistemology of Science***

- Feyerabend's account of science is based on non-exclusivist philosophy that opens the door for the construction of scientific knowledge for each individual who is learning science.
- It is impossible to view the progress of science in terms of one set of methodological rules that are always used by scientists: such as 'scientific method'.
- Science progress through ad-hoc guesses.
- Science knowledge is relative depending on the context and hence is tentative and dynamic.
- Scientific knowledge is constructed with the attitude of "anything goes" which is known as epistemological anarchism.

- Feyerabend's Revolutionary model holds the "theory of Anarchism". The construction of knowledge is a free path relative to an individual, his ways of discovering knowledge, his rationality, and his social setting.

### ***Feyerabend's Methodology of Science***

- Feyerabend's methodology of science is against a fixed scientific method.
- According to him, there is no universal rule or framework to be followed.
- His methodology is against the universalization of method, pattern, or path in the construction of scientific knowledge.
- According to Feyerabend, the methodology of progress in science focuses on individual rationality, uniqueness, and freedom of rational thinking.

### ***Laudan's Epistemology of Science***

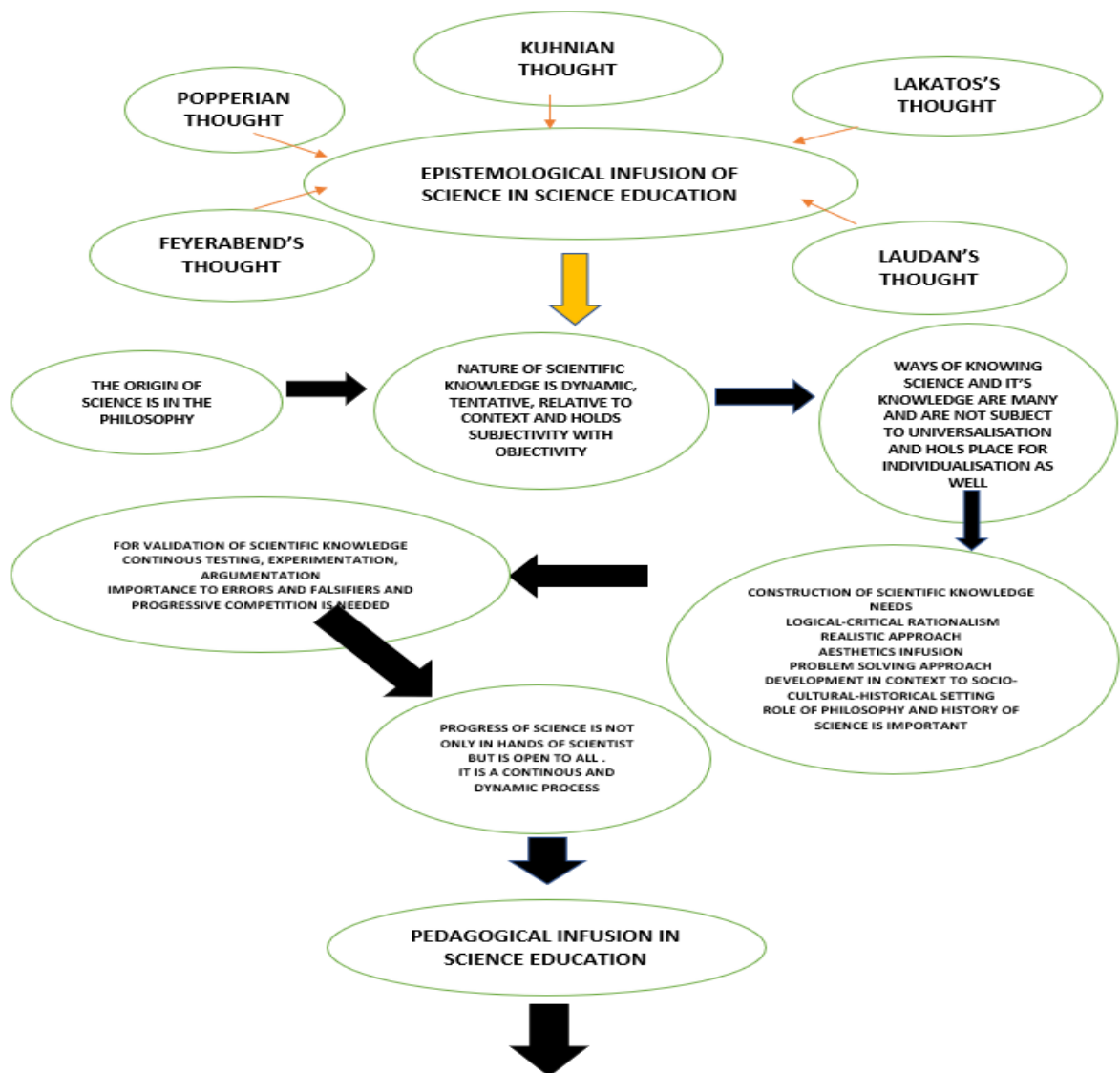
- Scientific knowledge and theories are seen according to their problem-solving effectiveness.
- The choice of theory is dependent on its relative rate of progress in comparison to other theories.
- The problem-solving effectiveness is the measure of progress in science.
- The aim of the construction of scientific knowledge is not truth but solving problems, empirical and conceptual.
- The evaluation of scientific theories is comparative in nature.
- Nature is relative, dynamic and subjective.
- Science holds subjectivity.

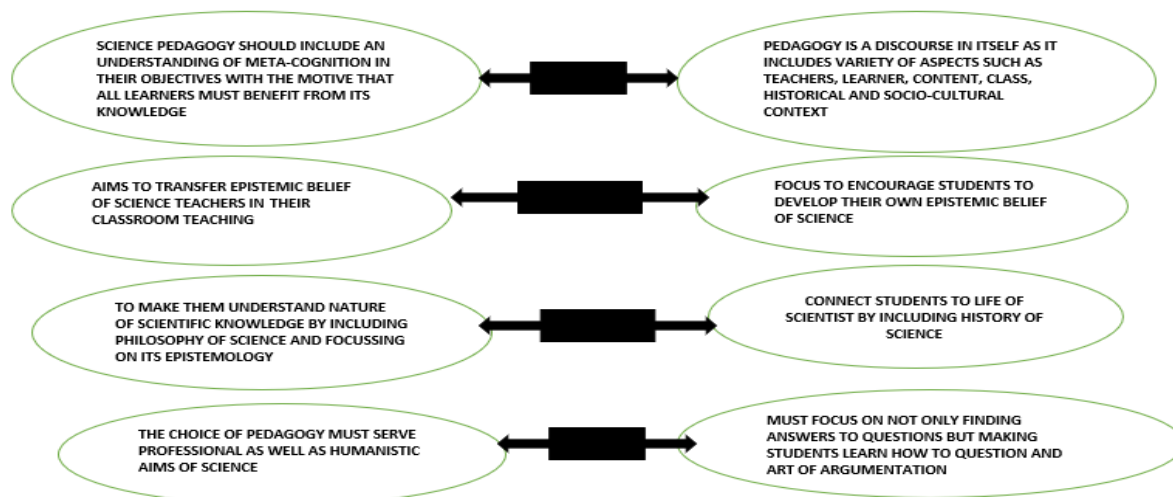
### ***Laudan's Methodology of Science***

- Laudan cannot substantiate that logical and epistemological criterion for determining the problems and their solutions that go on changing in the field of scientific research. Therefore, favours simple, easier, and clear ways of constructing knowledge.
- The maximisation of scientific progress constitutes the essence of scientific rationality.

- Any methodology in the progress of science will work that aims at problem-solving and providing solutions to the problem.

### Epistemic Pedagogical Framework from the Philosopher's Account of Science





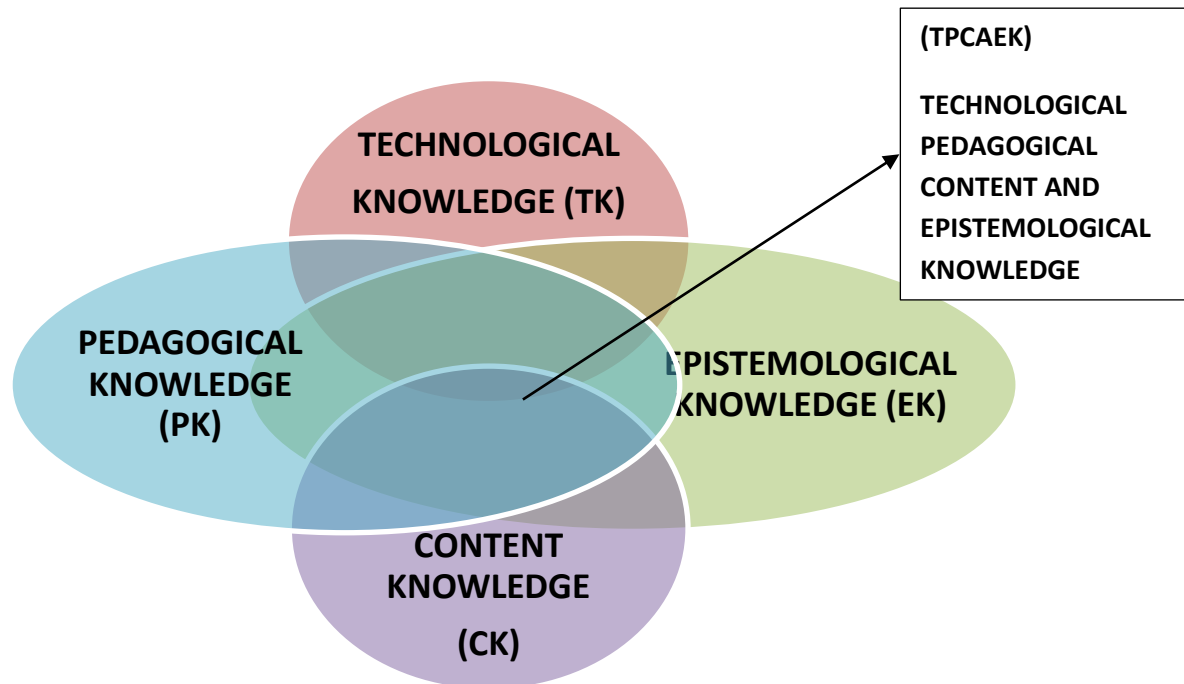
2) The findings of the second research question “What is the voyage of science education in context to pedagogical discourses in science” are:

- The voyage of science education has never been linear. It has been dynamic over the years in terms of learners, science instruction and science teaching-learning. As the perspective of science education changes, it affects the pedagogy as well.
- There is a symbiotic relationship between epistemology, the nature of science and pedagogy. All three influence each other. Generally, it is an epistemology that provides the conceptual framework and it affects the nature of science which in turn affects the pedagogical practices in terms of methodology. This relationship between the three in this research cannot be claimed to be always one way as doors are always opened for the probability that in some cases it could be a pedagogy that influences both the nature of science and epistemology.
- The teaching models of science are many as per the literature but which model to adopt depends on the need of the science educators. The science teaching models have a common feature that is they aim for the construction of scientific knowledge. The constructive approach is the core of every model and is also the very aim of science education to develop that. Along with the development of constructivism in students, a few other approaches must be developed in students learning science. The approaches can together build the pillars of scientific knowledge that science education should aim to conquer through teaching and learning science. These are:
  - Constructivism

- Critical Thinking
- Collaborative learning
- The pedagogy of science is dynamic in nature and still, a dynamism continues. The success of any pedagogy depends on how effective it is in achieving the aim of the topic being delivered. The choice of pedagogy depends on the subject content, learners, and skill of educators. No matter how many pedagogies we discuss in this study there is always a scope for many more. There are still many pedagogies that have shown a good impact on science teaching learning in developed countries but are still not being used in India. There is no absolute claim that a particular pedagogy will be proved helpful for every topic or every learner but there is a high need to know about the variety of pedagogies with the motive that any way to make science education more effective must not be skipped. The few new pedagogies and their related learning that helps in the construction of scientific knowledge are mentioned below:

Pedagogy	Related learning
Inquiry method	Discovery learning
Discourse method	Meaning making in science classroom
Demonstration method	Observation learning
Problem solving method	Exploration learning
Constructivism method	Critical thinking
Visual representation model (VRM)	Spatial reasoning approach
Pedagogical Content Knowledge	Mastery of content approach
Technological Content Pedagogical Knowledge	ICT approach
Game based pedagogy	Performance approach

## The New Pedagogical Model of Science



### The features of the model:

- The highlight of the model is the addition of a dimension “Epistemology” which is the most pertinent aspect of knowledge and its different dimensions.
  - The epistemology in this model covers: “Epistemology of the content/subject (here science), Epistemology of technology.
  - Epistemology of pedagogy
- The model highlights the relationship between epistemology and pedagogy, as epistemological knowledge of science as well as epistemological knowledge of pedagogy of science influence each other and for effective pedagogy epistemological knowledge is a must.
- 3) The research findings of the third research question, “What is the relationship between the teacher’s epistemic belief of science and his/her pedagogical practices in science teaching?” are:
- There is a relationship between science teacher’s epistemic belief and their pedagogical practices. This suggests that since both are related to each other and hence both should work in sync with each other for effective science education.

- Since epistemology and pedagogy are related, therefore, teachers must develop correct epistemic belief of science as that is what influence their pedagogy in class.
- The choice of pedagogy to be used and how it should be used must depend on the epistemic belief of science teachers.

**Objective 4:** To explicate the concept of Humanistic Aesthetics in Science. The objective intended to explore three research questions: Does Aesthetic play role in science? How can an educator offer opportunities for students to have Aesthetic experiences in the classroom? How does Aesthetics in a scientific idea play a role in the development of scientific thinking? **The main findings are as follows:**

- Aesthetics do play role in science and it plays role in science through its different dimensions. The dimensions that contribute to aesthetics in science are:
  - Feelings
  - Emotions
  - Intuition
  - Beauty
  - Truth
- Aesthetics plays an important role in the science classroom through the use of different entities, these are:
  - Doing science with aesthetic awareness
  - Use of Language game
  - Scientific images
  - Aesthetic dimensions
  - Emotions
  - Feelings (Anticipation, Wonderment and Bewilderment)
  - Aesthetic cognition
  - Aesthetic Perception
- The aesthetic experience in the science classroom are must and act as a base on which scientific thinking progresses, these experiences can be seen as:
  - Normative aesthetic experience
  - Cognitive aesthetic experience

- There are several common features in science which are involved in the construction of scientific knowledge and are part of the science classroom, these features could be connected to some emotions and hence must be used by educators in the same way to bring students close to emotions and feelings in science classroom which will automatically help to develop their aesthetic sensibility while learning science.

Common Features involved in the construction of scientific knowledge and Related Emotion/Feeling

Common features involved in a science chapter	Related Emotion/Feeling
Problem solving	Thrill or challenge
Analysis- Synthesis	Alert or aware
Critical thinking	Attention
Experimentation	Expectation & Wonder
Hypothesis	Anticipation
Argumentation	Motivation & Confirmation
Result/ Conclusion	Happiness/Accomplishment

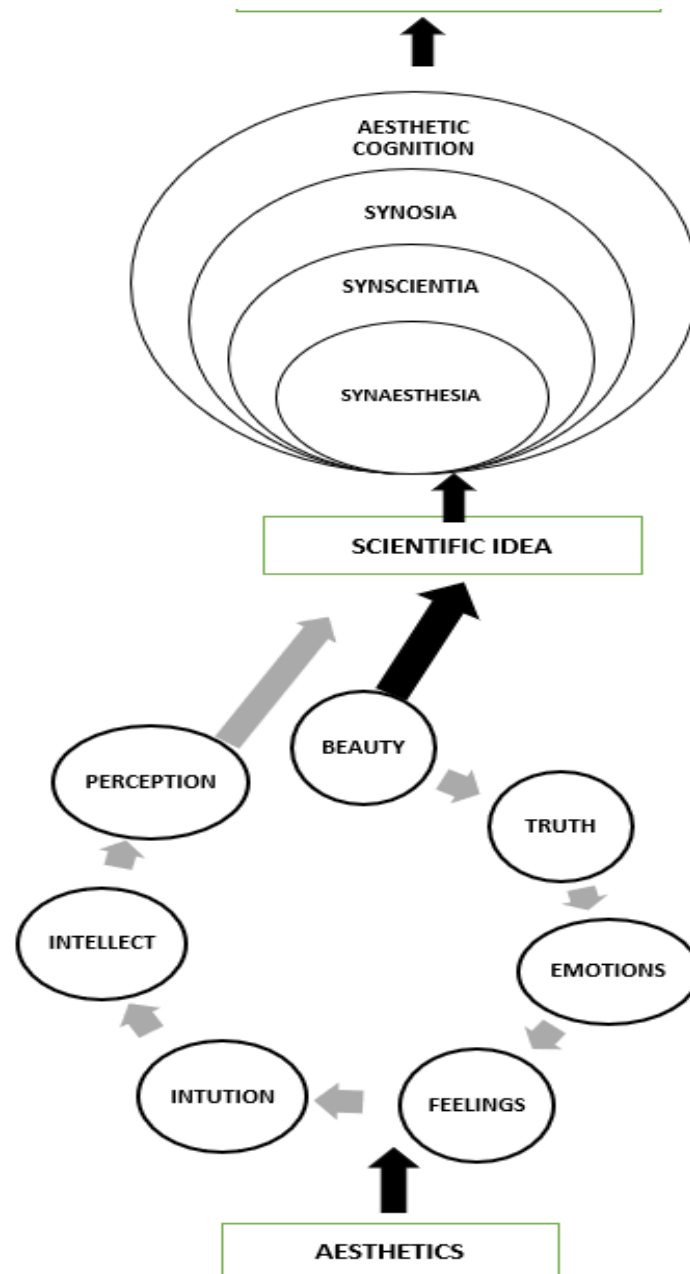
For the development of scientific thinking through aesthetics, there is working of “Aesthetic Cognition” which is also known as the meta-logic of aesthetic cognition and it combines knowledge and feelings into an experience which creates the basis of scientific thinking. The logic which is involved is of two types:

- Informal logic
- Formal logic

It is informal logic in which aesthetic aspects of science contribute the most. Aesthetic cognition is a pre-logic or informal logic which is necessary for the realization of different natural phenomena going around and this realisation triggers a scientific idea which leads to scientific thinking which is presented to the world with the help of formal logic.

- There are a few ways that should be followed to add aesthetic elements to the science classroom:
  - Setting the scene of the classroom
  - Choice of words
  - Linking to stories of a scientist who were artists and vice-versa
  - Connecting the topics outside the class
  - Doing science with emotions attached
  - Using a variety of methods for different topics
  - Movies or videos related to science
- Aesthetics and Science Education
  - Aesthetics leads to transformative experience in science education
  - Aesthetic experience is a must for instilling creativity in students.
  - Science is about studying nature and aesthetics is an inseparable part of nature, students will take more interest in science and the nature of this nature and science bond is touched upon.
  - Aesthetic perception and experience open doors for multiple realities and subjectivity, this helps students to adapt subjectivity when it comes to scientific knowledge, answers to science problems, sources of scientific knowledge and multiple ways to reach a solution.
- Aesthetic model of scientific thinking

The aesthetic model of scientific thinking is depicted below. According to the model the aesthetic dimensions such as feelings, emotions, intuition, beauty, and truth act as an initiator of a scientific idea and this scientific idea acts as a foundation from which scientific thinking grows. As a scientific idea is produced, the next experience is a blend of the aesthetic dimensions, the scientific idea, and the intellect. The combination of aesthetics and cognition gives rise to “Aesthetic Cognition” and aesthetic cognition which is also known as “meta-logic” with the help of two forms of logic pre-logic or informal logic and formal logic leads to scientific thinking.



### Other Reflections of the study

- Blend of Science and Aesthetics: Towards A Humanistic Science Education

The different art mediums such as novels, movies and shows which are based on science and scientific discoveries must be shown to the students. The students will not only enjoy these different sources of learning but these sources will enhance creativity and imagination in science.

Table of Sources reflecting Science and Aesthetics together Science

Science Fiction Novels	Science movies	Shows
<ul style="list-style-type: none"> <li>• Frankenstein (a first science fiction novel)</li> <li>• Ray Bradbury’s “A sound of Thunder”</li> <li>• Soul of science Interstellar Enlightenment Now by Steven Pinker</li> </ul>	<ul style="list-style-type: none"> <li>• A beautiful mind</li> <li>• The man who knew infinity</li> <li>• The Imitation game</li> <li>• Good will Hunting</li> <li>• The Martian</li> <li>• Dead poet’s society</li> </ul>	<ul style="list-style-type: none"> <li>• Bill Nye</li> <li>• The science guy and cosmos</li> </ul>

• **Striking in through the Myths: Reshaping of Science Education**

Myth1: Scientific knowledge holds absolute objectivity

To be precise and straight the very nature of science and scientific knowledge is tentative. Though, there is no doubt that like every other knowledge science aims for careful procedure and minimum errors in the way the construction of knowledge but to claim that scientific knowledge is objective is a myth. From Karl Popper’s accounts of science, it is evident that according to him science progress with the notion of conjectures and refutations in which the direction of work is to refute these conjectures one by one Popper suggests that the absence of contrary evidence, demonstrated through an active program of refutation will provide the best support available (Popper, 1963) many scientists do support this notion of popper on the way science advances. Therefore, one of the most revolutionised philosophers of science, Popper gives the idea of continuously falsifying the conjectures till when we are not able to find one which could not be refuted for time being at least. Hence, science and scientific knowledge from their very nature cannot claim absolute objectivity. Furthermore, not only Popper, even Kuhn, Feyerabend, and Laudan do not stand with absolute objectivity as already discussed in the previous chapters. In addition to this, the theories, laws and scientific knowledge is created by a human being “the scientist”. Therefore, every scientist is own way of looking at the world, his biasness, and perspective is part of the knowledge he is producing. In the words of Hodson (1986), the inability of scientists to be objective is

found in theory-laden observation, a psychological notion. Hence, the claim that science and scientific knowledge holds absolute objectivity is a myth.

Myth2: Scientific knowledge is constructed through a general and universal scientific method.

The notion that is commonly attached to science is that it progresses through pre-set steps of the scientific method. These steps listed for the scientific method vary somewhat from text to text but usually include: a) defining the problem, b) gathering background information, c) forming a hypothesis, d) making observations, e) testing the hypothesis and f) concluding. The sad part is that these steps were initially presented innocently enough when Keeslar (1945a/b) prepared a list of several characteristics associated with scientific research such as establishing controls, keeping accurate records, making careful observations and measurements but now have reached science textbooks and stick in minds of science stakeholders and is being practised widely. This common notion is not only confined to science education but even in the world of research, especially in social sciences and humanities research, there is a common notion that one of the main characteristics of research is that it is scientific in nature and hence it has a fixed pattern to proceed and that's the very reason till today in India maximum researches are stick to the same steps of research. The truth is far from this, the philosophers such as Paul Feyerabend as discussed in the previous chapter of his account of science was against the universal method of construction of scientific knowledge and rationalism. His theory of "Anarchism" which stands for the notion of "anything goes" stands completely against any such universalisation of science and its progress. Different studies focus on scientists at work that have shown that no research method is applied universally (Carey, 1994; Gibbs & Lawson, 1992; Gjertsen, 1989 as cited in McComas, 1998). This notion of the universal scientific method has so strongly reached science education and is so pervasive that many students must be disappointed when they discover that scientists do not have a framed copy of the steps of the scientific method posted above each laboratory workbench.

Myth 3: The term "Hypothesis" is an educated guess.

In the progress of science "hypothesis" as a term is commonly used and is defined in very textbooks as "an educated guess" "tentative statement" or "tentative solution",

firstly the third notion of “tentative solution” is completely wrong as a hypothesis in no way says anything about the solution of the scientific research problem. The other two notions raise the question that an educated guess of what? the truth is hypothesis is neither the educated guess of the problem nor the tentative statement of solution. The reason is simple and logical because hypothesis in science since a decade is being used in different contexts by scientists and it has a variety of meanings. For example, when Newton come up with his law of gravity he stated that he has framed no hypothesis by this he means that he had no speculation about an explanation of why the law of gravity operates as it does. In this instance, Newton used the term hypothesis as “an immature theory”. Secondly, the term hypothesis is used as a tentative statement which is accepted and rejected as the research proceeds but does this acceptance or rejection of these statements convey the unquestionable results or solutions? The answer is no. Hence, if it’s not possible to remove the term hypothesis from the science education being imparted but it is essential to remove the myth that surrounds the word. As a solution to the hypothesis problem, Sonleitner (1989) suggested that tentative or trial laws be called generalizing hypotheses with provisional theories referred to as explanatory hypotheses. Another approach would be to abandon the word hypothesis in favour of terms such as speculative law or speculative theory. With evidence, generalizing hypotheses may become laws and speculative theories become theories, but under no circumstances do theories become laws. Finally, when students are asked to propose a hypothesis during a laboratory experience, the term now means a prediction. As for those hypotheses that forecast, perhaps they should simply be called what they are, predictions.

Myth 4: The construction of scientific knowledge follows the sequence: Hypotheses turn into theories and theories turn into Laws.

This notion grows with the belief that with an increase in the number of shreds of evidence collected through various experiments the scientific ideas developed into accepted knowledge by this sequence. The myth is so firm in minds of people that even the former U.S. president expressed his misunderstanding of science by saying that he was not troubled by the idea of evolution because it was, in his words, “just a theory.” The president’s misstatement is the essence of this myth; an idea is not worthy of consideration until “lawless” has been bestowed upon it (McComas, 1998). The truth is entirely different the theories and laws are different kinds of knowledge but

misconception portrays them to be different forms of the same construct of knowledge. The theory could be said to explain laws as the application. Laws are generalizations, principles or patterns in nature and theories are the explanations of those generalizations (Rhodes & Schaible, 1989; Horner & Rubba, 1979; Campbell, 1953 as cited in “cookbook science” and explanations or theories as “theoretical science”).

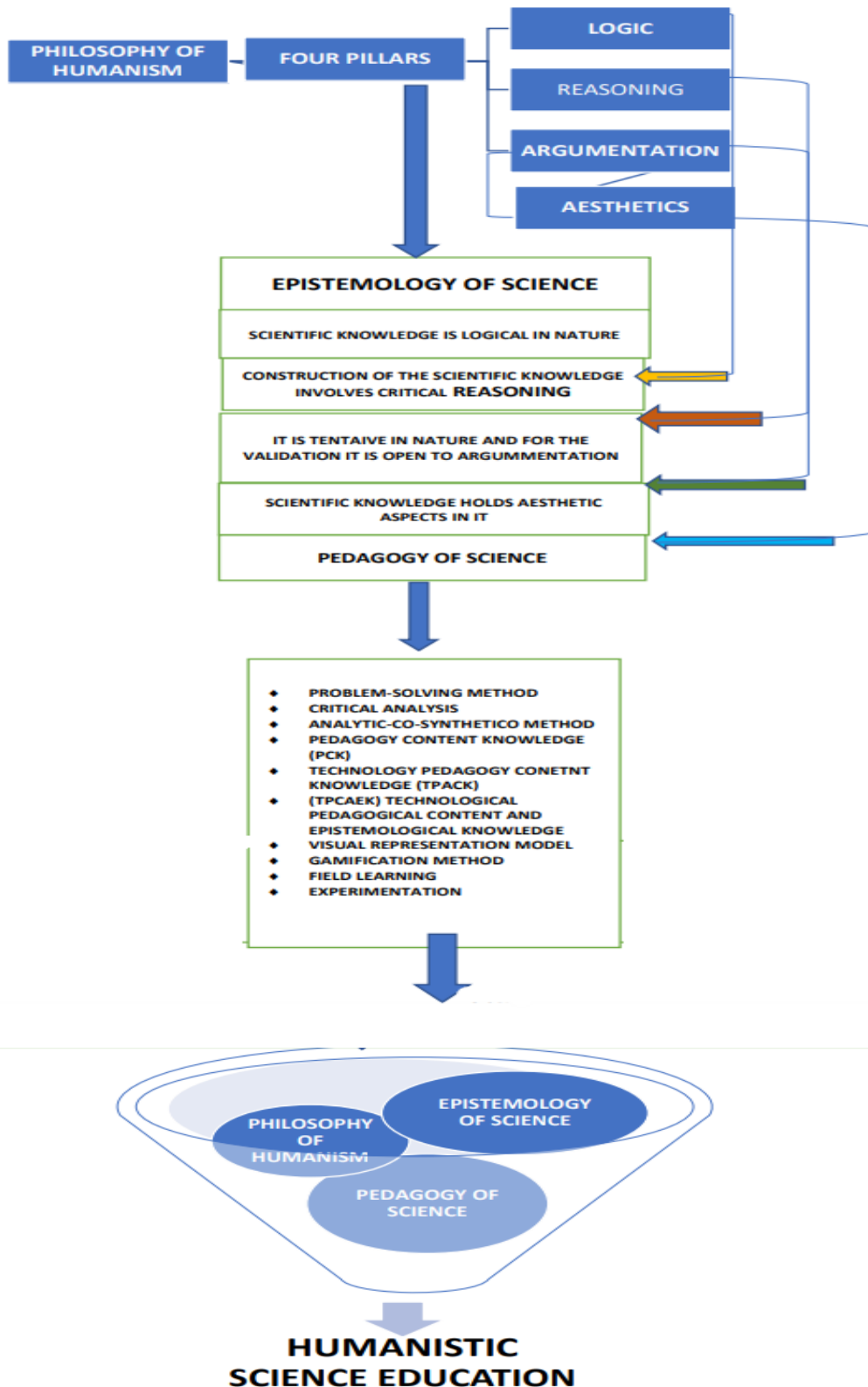
Myth5: Aesthetics is confined to Art and its related discipline and is far away from science.

This notion is one of the most obvious notions people have about science that it is not even thought about. The answer to this myth is very deeply discussed in the chapter “Aesthetics in science” of the study but this single argument is strong enough to clear the doubts, that science is the study of nature and aesthetics is an inseparable part of nature. Hence, how beauty can be skipped from nature and how nature could be skipped from the construction of scientific knowledge. Therefore, it plays an important role in the progress of science and the construction of scientific knowledge by using different aesthetic entities such as aesthetic perception, emotions, feelings, aesthetic cognition, aesthetic dimensions, visual images etc.

Myth 6: Scientific knowledge is impersonal and is far from being humanistic.

This notion is one of the main reasons for this study. The question is “who has created science” and “who leads to the construction of scientific knowledge”, the unanimous answer is “man” hence, the argument is how something that is created by man can be impersonal and lack a humanistic element in it. These examples of several types of research, and statements of scientist that are discussed in the chapter “Science and humanism” of the study reflects that science is and has always been a humane thing and always has a personal touch whether, in terms of choices, preference, feelings, emotions scientist goes through while construction of scientific knowledge.

• **Rehumanising Science: Transaction between Philosophy of Humanism and Science**



### **Educational Implications of the Study**

- The understanding of any discipline including science is incomplete without understanding the epistemology of that subject. Though, the study of the true epistemology of science is conveyed as how important is to understand the epistemology of science while imparting science education. The knowledge and understanding of epistemology are not only restricted to students but teachers themselves need to work to modify their epistemic beliefs to have epistemic convictions in the right direction.
- Science is a dynamic and evolutionary discipline that is often surrounded by many myths. Therefore, there is a need to clear the clouds of myths that are part of science culture nowadays. Hence, the study helps the reader to clear many such discussed myths and most importantly will give them a critical approach to first validate the circulating notions about science before accepting them and conveying them further.
- The study has discussed the pedagogy of science and how the pedagogy of science has shaped itself over the years. It will help teachers to understand the concept and nature of pedagogy and will encourage them to use different pedagogies in their classrooms which should be as innovative and enriching as the discipline of science is in itself.
- Science is a subject of creativity, imagination, and newness along with logic and reasoning intact in it. Hence, the creative and imaginative side of science must be encouraged in students and teachers as well while imparting science education. The new ideas coming from students must always be welcomed and students must be encouraged to have their own epistemic beliefs and construct scientific knowledge after validating it thoroughly.
- Aesthetics is an inseparable part of science; therefore, science educators must give different opportunities to unwrap this aspect of science while teaching. It will not only enhance their affective domain but will also help them to come up with new scientific ideas that will contribute to the construction of scientific knowledge.
- Though science is an older discipline but always carries its youngness along due to its evolutionary nature, similarly the way science should be imparted in the

classrooms today must carry this spirit of science in terms of its pedagogy and other related aspects.

- Science and scientific knowledge is not constructed in isolation. There is the influence of different dimensions in it namely its main stakeholders, teaching, learning, sociohistorical aspect, culture, and social setting. Therefore, science and scientific knowledge must be considered as a cultural, historical, and social discourse in itself and hence its construction should be in context to the socio-cultural setting.
- Science has somewhere lost its humanistic nature while focussing on its professional aims and hence science must be taught with a humanistic touch in it and with the aim of human welfare in context to the philosophy of humanism and science where rationality is the centre, democracy of human being is the base and sovereignty of the human being is at the apex.
- The most important implication of the study is to provide insight and add different perspectives to the mind of the science stakeholders which include science curriculum designers, textbook creators, educators, students, and readers according to which science and scientific knowledge must be looked upon and should be further progressed. These different perspectives include emotions, aesthetics, philosophy, history and above all humanism in science.

### **Conclusions & Discussion: A Postscript of the Study**

The motive of the entire study is not to claim any generalisation. The motive is simple and straight to give an insight to the readers on how from different perspectives science can be touched upon and to rehumanise science with the help of three main components namely philosophy of humanism, epistemology of science and pedagogy of science. There is no doubt that at first even the idea to humanise science may not corroborate and contradict the ‘common sense’ notion about science that science is a mechanical enterprise and aims at the objective truth. The term objective, objectivity, and impersonal are often used when science and scientific knowledge is discussed and words such as ‘Humanistic’, ‘personal’ and ‘subjective’ are considered myths, illusions, prejudices and similar other experiences. This leads to false epistemic belief about science and scientific knowledge and its effects are been noticed in science education as well. The epistemic belief of both teachers and

students and the pedagogical practices used to impart science education reflect these false claims and lead to the construction of scientific knowledge in the wrong direction. This study is a small effort to clear the clouds of myths such as objectivity, mechanical entity, impersonal aspects etc. that surround science and give way to 'subjectivity' and 'humanism' to reach science. Initially, it was noticed the world of science has been divided into two groups of philosophers, the one group includes philosophers such as Nagel, Carnap, Hempel etc. who accepted that objectivity holds an epicentre position in well-established scientific knowledge. They propagate the common notion that scientific knowledge holds unconditioned objectivity in it whereas the other group of philosophers include Toulmin, Feyerabend, Kuhn, Polanyi etc. who stands with the 'subjective' notion of scientific knowledge. It was evident that the formal group is influenced by positivist and empiricist views. According to them, scientific knowledge is purely objective and its interpretation is based on formal inferences, deductions and generalisations. The latter group believed that the progress of science is not completely based on set logical rules and objectivity and that there is a role of psychological and subjective aspects. The notion that 'unconditioned objectivity' in science is not possible to achieve as science and its progress cannot be separated from personal and subjective touch which is humanistic in nature. The history of science conveyed a strong example of the great scientist Newton that his discoveries left the impression that there were no assumptions in his physics which were not supported by experimental evidence and he has not framed any hypothesis but deduced the basic concepts and laws only from his experimental findings. Though this was a long-lasting dream of some philosophers to attain pure knowledge which is real and objective but soon different research and investigations gave doubt about Newtonian principals. This arises a strong argument that if objectivity in science must be believed then why once objectively claimed scientific knowledge from scientists as great as Newton questioned and investigated? In the words of Heisenberg, "the hypothetical substance 'ether' which has played such an integral role in the early discussions on Maxwell's theories in the 19th century had been abolished by the theory of relativity" (Heisenberg, 1958 as cited in Oldofredi & Esfeld, 2019). The discovery of Quantum theory also brought many pertinent modifications and reassessments at the foundational level of the natural sciences. There is an end number of such examples in the history of science and these

examples suggest no matter how strongly we claim scientific knowledge to be objective but still absolute objectivity or unconditioned objectivity is neither possible nor what science aims to achieve. Further, it was seen another false epistemic belief that surrounds scientific knowledge is that it is claimed to be “impersonal” but the argument is when that science in itself is a creation of man so how it could be claimed to be impersonal? In the very first research done on the existence of this universe, it was impossible to grasp and understand the complete universe at once hence the scientist first use his special perspective and saw the universe from his personal space according to his choice and preference. As discussed in the chapter on aesthetics in science the scientist according to his likes and dislikes claim a particular theory to be more beautiful than others and prefers his claims as best in comparison to other claims. One of the most important steps in the construction of scientific knowledge is “formulation of hypothesis,” this in itself is a statement of personal faith and the selection of a hypothesis to be put to test is a personal choice. These terms choice, like, preference, faith, and feeling all indicate personal touch in science. Personal knowledge contributes to the framing of knowledge structure and the construction of personal epistemic belief., Michael Polanyi in his work on personal knowledge maintains that scientists become ‘subsidiarily aware’ and some amount of ‘personal participation in all scientific discoveries is present (Polanyi, 1966 as cited in Festre & Ostbye, 2020). Hence, scientific knowledge is personal in nature and the claim that it is impersonal is false. In addition to this, science always needs a man for its creation, communication, and utilization. The philosophy and history of science cannot be traced back without human efforts. In the words of Carl Rogers, “Science has its inception in a particular person who is pursuing aims, values, purposes, which have personal and subjective meaning for him” (Roger, 1955). Therefore, aspects such as personal, subjective, and humanistic are inseparable from science as long as a “scientist” is a man and its follower and user are “human”. The humanistic touch in science is inseparable from it and the humanistic perspective in science not only gives science a subjective and personal view but it also bestows light on the creative side of science and scientific knowledge. Though we do not deny the importance of objectivity in rule of deductions and generalisation in scientific procedures but for the creation of original ideas, there is must need to give importance to creativity and imagination in science.

Creativity is an important product of the humanistic perspective in science which gives space to subjectivity in science. The two discussed philosophers Karl Popper and Thomas Kuhn have their own different epistemic beliefs but both are concerned “with the dynamic process by which scientific knowledge is acquired rather than with the logical structure of the products of scientific research (Roy, 2003). The other three philosophers Imre Lakatos, Paul Feyerabend and Larry Laudan all give importance to the dynamic, tentative and utility aspects of science. Therefore, the process to reach scientific knowledge is personal, subjective, and humanistic in nature. In the end, I would like to mention the words of D. Hawkins in his work “the creativity of science” that “what is lacking in the official account of science is a sense of the inwardness of science, of its creative impulses and its intellectual growth, of its pettiness and its greatness- in short, of the human character of science” (Hawkins, 1958 as cited in Roy, 2003). Throughout this entire study, the effort has been made to sensitize the stakeholders of science and science education to rehumanise the so long estranged product of man which is known as ‘science’ and return its robbed glory of human character which is subjective and personal and holds aim of human welfare at the top with the help of philosophy of humanism blended whole-heartedly with science and scientific knowledge.

### **Future Suggestions**

Before I conclude, my work first I wanted to offer directions for future research. My work has only been able to capture the epistemic discourse of five prominent philosophers of science and the work majorly provides a conceptual and theoretical framework of account of science from the lens of the philosophy of humanism. This work can be conducted under alternative methodologies. There is also a scope to explore other different philosophers of science whose thoughts have revolutionised science from time to time. The explorations reported in the thesis are preliminary, and sticking to the spirit of this work, I think their strengths lie in opening up theoretical and empirical questions for future work to explore.