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The Pre-Needham Question: Origins and Evolution of Eastern Rationality and Fa-Yi Thought in Engineering Education

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ABSTRACT

This paper proposes the "Pre-Needham Question," redirecting inquiry from "why modern science did not develop in China" to "where the rational tradition that sustained ancient China's long-leading science and technology originated." Through a dual-evidence approach combining textual research and archaeological findings, this study traces Mohist Fa-Yi rationality from ancient artisan practice, revealing that nearly ten millennia of *Fa-Yi*-related practice cultivated proto-standardized awareness, and that Yu the Great, the Baigong artisans, and Mozi established an Eastern rationality lineage: large-scale practice → artisan norms → *Fa-Yi* philosophical theory. Mohist *Fa-Yi* rationality gave rise to three engineering education models: "self-rectification through the ink line" as self-correction; the Three Criteria method as assessment-procedure; and "observing craftsmanship, transmitting norms, inquiring into causes, and assessing suitability" as causal-inquiry. These forms differ critically in transmission: the first, tool-dependent, continues today but remains operational; the second, sharing affinity with Confucian culture, suffered methodological discontinuity; the third, dependent on the most complete school-based system, was severed after Mohism's decline. The deeper value of *Fa-Yi* rationality is that engineering practice itself constitutes the origin of epistemological thinking. Eastern rationality is not an "incomplete version" of Western rationality, but another rational tradition with an independent path of development. In the AI era, when systems can perform "observing craftsmanship" with precision beyond human capability, pursuing causal laws, assessing appropriateness, and making ethical decisions will become the irreplaceable core of human engineering.

Keywords: Needham Question, Fa-Yi, Mohism, Eastern rationality, engineering education thought, Kaogongji, Yu the Great, epistemology of engineering practice

INTRODUCTION: THE PRE-NEEDHAM QUESTION

The Problem Structure of the Needham Question

In 1954, Joseph Needham posed in the preface to Science and Civilisation in China the famous proposition later known as the "Needham Question": "Why did modern science not develop in China?" (Needham, 1990). This question quickly became a central issue in the history of science, stimulating more than seventy years of sustained debate among scholars.

Yet examining its problem structure reveals the inherent Eurocentric bias of this proposition: it frames the scientific and technological achievements of ancient Chinese civilization as a "failure to develop modern science," while implicitly taking the Western Scientific

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Revolution as the only legitimate path to modern science. Professor Sun Xiaochun has conducted systematic critical reflections on this point, noting that the "negative problem" formulation of the Needham Question conceals a logic of Eurocentrism, a judgment that strikes precisely to the heart of the matter (Sun, 2024).

What is particularly intriguing is that the Needham Question's framework also contains a "affirmative claim"—that "between the first century B.C. and the fifteenth century A.D. Chinese civilization was much more efficient than the West in applying human knowledge of nature to practical needs" (Needham, 1990). This "affirmative claim" was taken for granted and thus overlooked in scholarship for nearly seventy years. The question of "why China once led the world" remained on the periphery of academic research.

The Proposal of the Pre-Needham Question

This paper proposes the Pre-Needham Question, whose structure is: before asking "why modern science did not develop in China," first ask "why ancient Chinese science and technology led the world for so long"; and after asking "why it was ahead," then ask "where did the rational spirit of Mohism, which represents the peak of ancient Chinese science and technology, originate."

In Needham's magnum opus Science and Civilisation in China, Mohism is a conspicuous presence. In terms of epistemology, Needham particularly emphasized that the Mohists "did not distrust human reason at all, clearly laid down what could have become the fundamental conceptions of natural science in Asia" (Needham, 1990, p. 172). He devoted a special chapter to the natural-science content of Mohist learning and gave high praise to Mohist logic, observing that "The whole flavour of these passages is Aristotelian—a remarkable parallelism in time since the Mohist logicians were working just about the time of his death (322 BCE)" (Needham, 1990). He further noted "how far the later Mohists went in the building up of a thought-system on which experimental science could have been based" (Needham, 1990). In his view, "one is tempted to think that perhaps the greatest tragedy in the history of Chinese science was that Taoist naturalist insight could not be combined with Mohist logic" (Needham, 1990).

In these discussions, Needham keenly recognized the distinct rationality of Mohism, its representativeness in the East and Asia at large, and the parallels and divergences between Mohist and Western rational traditions. However, he did not fully explore the origin of this rational spirit and intellectual system. This is precisely the task that the second level of the Pre-Needham Question is intended to take up and develop further.

Core Thesis: The Engineering Origins Hypothesis of Eastern Rationality

The core thesis of this paper is: the Eastern rationality system represented by Mohism originated from craftsman operational procedures that could be transmitted across generations, and is intimately related to *Fa-Yi*. If this thesis is valid, three implications follow:

1. Epistemologically: ancient Chinese rationality was not merely a product of abstract philosophical speculation; operational rationality grounded in material practice qualifies as a foundational source of human rationality (*Here the concept of cāo zuò lǐ xìng (operational rationality) is explicitly distinguished from Max Weber's Zweckrationalität (goal-oriented rationality). While Weber's concept focuses on the rational choice of means to achieve predetermined ends within the framework of social action, the operational rationality discussed in this paper refers to the systematic, repeatable, and norm-governed procedures embedded in material engineering practice*).
2. History of engineering science: there was no discontinuity between technology and science in ancient China; Mohist engineering practice and scientific discovery were already fused within a single epistemological system.
3. Contemporary engineering education: the *Fa-Yi* rationality embodies a unified structure of "concept–instrument–outcome", an objective standardbased evaluative logic, and a methodological commitment to deriving causal laws from engineering practice. It thus provides Eastern intellectual resources for building an independent epistemological foundation for modern engineering education, offering a historic chance for revival in the AI era.

THE FA-YI ENGINEERING EDUCATION TRADITION: FROM YU THE GREAT TO THE BAIGONG ARTISANS AND MOZI

Existing research on the origins of Mohism indicates that Yu the Great, the Baigong artisans, and Mozi share profound connections, forming an engineering thought continuum (Fang, 2017; Xu, 1998). Further analysis of textual sources reveals that the engineering connections among the three are concentrated in the tradition of instrument and tool usage (such as the compass, square, plumb line, and water level).

"Fa-Yi" in the Mozi and the Baigong System

The "*Fa-Yi*" chapter of the *Mozi* opens with a striking contrast:

"Those who undertake affairs in the world cannot do so without standards *Fa-Yi*). Without standards, yet able to succeed in their affairs—there has never been such a case. Even those who become scholars, generals, or min-

isters all have standards; even the Baigong artisans in their work all have standards. The Baigong make squares with the carpenter's square (ju), circles with the compass (gui), straight lines with the inked string (sheng), level surfaces with the water level (shui), and perpendiculars with the plumb line (xuan). Whether skilled or unskilled, all artisans take these five instruments as their standards. Yet when it comes to the great task of governing the world, or next to that governing a large state, if there are no laws and standards, this is less discerning than the Baigong." (Sun, 2021)

Mozi here highlights a critical fact: by the Spring and Autumn and Warring States periods, the Baigong craft community had already developed a highly mature *Fa-Yi* tradition. Skilled and unskilled artisans alike uniformly used the same five instruments—ju (carpenter's square), gui (compass), sheng (ink line), shui (water level), xuan (plumb line)—for quality control. This depersonalized normative consciousness allowed much engineering knowledge to become publicly teachable and testable via standardized methods, rather than remaining esoteric craft tied to individual genius.

Why, then, are the Baigong associated with *Fa-Yi*? The Kaogongji provides the answer.

The Baigong were government artisans engaged in the quality assessment and screening of civilian implements, subordinate to the Minister of Works (Sikong) (Liu, 2015). The Kaogongji opens with the statement: "The state has six duties, and the Baigong constitute one of them. They took charge of examining the curved and straight forms along with their textural properties, processing the five materials, and appraising the implements for the people by quality assessment." Zheng Xuan's commentary notes: "The Baigong are subordinate to the Minister of Works (Sikong).... The Minister of Works is charged with constructing city walls and ramparts, establishing capitals and settlements, erecting *altars of soil and grain and ancestral temples, and building palaces, vehicles, garments, and implements..."* (Wenren, 2021).

The quality assessment of civilian implements necessarily requires instruments. The Kaogongji stipulates that those who can skillfully use the compass, square, water level, plumb line, capacity measure, and steelyard weight are called "state-certified artisans" (guogong), explicitly making instrument operation capability the certification standard for artisans of national standing (Wenren, 2021). To a certain extent, this may be regarded as China's earliest craftsmanship qualification system.

The Zhou dynasty had already attained a high level of standardized instrument usage. *The inscription on the Li clan measure in the Kaogongji reads: "Observing the markings and reflecting deeply, truly attaining the highest standard; the fine measure is now completed, to be displayed throughout the four states, to enlighten posterity forever—this instrument is the standard." This inscription describes the artisan's pursuit of ultimate casting quality for standard measures, emphasizing their universality ("to be displayed throughout the four states"), educational function ("to enlighten posterity forever"), and institutional character ("this instrument is the standard") (Wenren, 2021). This is consistent with Mozi's description that "all Baigong in their work have standards."* Yet where did the Baigong's "standards" come from? This requires us to trace further back.

Yu the Great's Flood Control and the Zhoubi Suanjing

Although the *Kaogongji* was incorporated into the Rites of Zhou, the Sikong-Baigong system was not originated in the Zhou period. Archaeological evidence indicates that the Baigong system continued from the Xia and Shang through the Western Zhou (Han, 2010; Tang, 2017). Taosi, Erlitou, Yinxu, and Zhouyuan sites have all revealed clear and continuous archaeological remains of handicraft industries, demonstrating the institutionalization of state-operated handicraft production. Shun appointed Yu as Minister of Works (Sikong) upon the recommendation of the assembly, and Yu thereby began flood control. The Book of Documents (Shangshu), the Records of the Grand Historian (Shiji), and other texts record that "Bo Yu served as Sikong" (Yu, 2008). The event of Yu controlling the floods is corroborated not only by literary records but also by the bronze inscription on the Suigong Xu: *"Heaven commanded Yu to spread the land, follow the mountains, and channel the rivers."* (Yu, 2008).

From the perspective of engineering education, the SikongBaigong system ensured that engineering knowledge and skills were no longer scattered individual expertise, but systematically transmitted and standardized through staterun workshop institutions.

Yu's approach to controlling the floods was to follow the mountain terrain, guide the water channels according to their natural tendencies, and facilitate the discharge of floodwaters. This required large-scale engineering surveys of terrain elevation and measurement methods. *The Shiji records that Yu "traversed the mountains, erected wooden markers, and fixed the locations of the high mountains and great rivers," reflecting the surveying activities of the time—setting up wooden poles as benchmarks, establishing elevation signs along mountain ridges and river courses, and determining terrain and watercourse positions.*

The Book of Documents contains similar records: "Yu divided the land, followed the mountains, made marks on trees as surveying markers, and

fixed the high mountains and great rivers." The Shiji also depicts Yu's working scene as "the level and plumb line in his left hand, the compass and square in his right, and the four seasons in his observance." This indicates that Han dynasty historians believed instruments such as the plumb line and carpenter's square had already appeared in Yu's time.

China's oldest mathematical classic, the Zhoubi Suanjing, records the dialogue between the Duke of Zhou and Shang Gao: *"The principles of mathematics are derived from the circle and the square. The circle is derived from the square, and the square from the ju [carpenter's square]. The ju is derived from the fact that nine times nine is eighty-one. Thus one bends a ju, making the base three, the altitude four, and the diagonal five. Having made a square [on the diagonal], take half of one rectangle. Going round and joining them together, one obtains [the figures of] 3, 4, and 5. The two squares together have the number twenty-five; this is called the accumulated square. Thus the numbers and mathematics by which Yu brought order to the world were born from this very practice."* (Cheng & Wenren, 2012) (*The final clause '此数之所生也' is rendered here as 'the numbers and mathematics…were born from this very practice' to reflect the grammatical direction of the original: the practice of flood control is the source from which numbers/mathematics are generated. This reading supports the paper's epistemological claim that mathematical knowledge emerged from engineering practice*)

This dialogue attributes the development of geometric mathematics to Yu's flood control practice, while also revealing a key ontological proposition—numbers arise from the carpenter's square, rather than the carpenter's square arising from numbers. The Art of War by Sunzi states "the earth gives rise to measurement, measurement gives rise to quantity, quantity gives rise to numbers, …" which is analogous. This indicates that in the view of ancient Chinese scholars, the fundamental principles of geometry were not derived from abstract speculation, but were generated from the operational practice of engineering measurement instruments (ju, gui, sheng, shui, xian). This proposition also possesses epistemological value—engineering is a domain that can generate knowledge on its own; artisan communities are not passive recipients of knowledge, but active generators of knowledge through operation.

Recent archaeological findings have provided material corroboration for the accounts in Zhoubi Suanjing. The gnomon-astronomical system unearthed at the Taosi site in Shanxi is a complex measurement system centered on instruments such as the gnomon ruler, shadow pole, and observatory platform. Its form and shadow-measurement methods are consistent with the records in the Zhoubi Suanjing, exhibiting significant mutual corroboration (Feng, 2013). This demonstrates that the Zhoubi Suanjing preserves an astronomical measurement tradition dating back to pre-Xia times. Erecting the pole to measure shadows involves horizontal calibration, vertical calibration, determining the midpoint, determining right angles, azimuth calibration, similar triangles, projective geometry, fractional proportions, and other measurement knowledge, containing the fundamental ideas of geometric mathematics and physics. For Yu's work of 'following the mountains and making marks on trees as surveying markers,' all this knowledge was necessary." The transmission and dissemination of such knowledge required some initial form of engineering education.

From an engineering logic perspective, the engineering activities of Yu's time were already highly complex, giving rise to demands for an instrument measurement system. For example, Longshan period city sites and architectural foundations generally exhibit north-south orientation, such as Pingliangtai, Erlitou, and Wangchenggang (Zhang, 2020), indicating that the pole-erection shadow-measurement technique for determining orientation was already widely disseminated at that time. The eggshell-thin black pottery stem cups of the Longshan period have rims approximately 0.3 millimeters thick, meaning that artisans could control the swing amplitude of the fast pottery wheel to at least within 0.2-0.3 millimeters (Zhao, 2016); Erlitou artisans had already mastered conscious alloy proportioning technology, controlling the proportions of copper, tin, and lead added according to the intended use of the vessel (Jin, 2000). These quantitatively controlled engineering activities could not have been sustained without some metrological method.

The Yu-Baigong-Mozi Lineage

Yu first served as Sikong to organize artisans in flood control, and later founded the Xia dynasty. Literary and archaeological evidence shows that the Baigong community continued through the Xia, Shang, and Western Zhou periods. From the perspective of intellectual lineage, the Baigong practice of examining civilian implements with instruments such as the compass and square can be regarded as the continuation and development of Yu's "plumb line and carpenter's square in the left hand, compass and square in the right" *Fa-Yi* practice—from the scope of mountain and river engineering geography, penetrating into the scope of carriages, ritual vessels, palaces, and weapons, becoming a normative consciousness of standards that actively drove standardization in artifacts and social institutions.

The connection between Mozi and the Baigong is documented in numerous textual clues. Mozi himself was skilled in carriage construction and likely came from a carriage-maker family (Zhang, 2022). His writings frequently mention the Baigong (in chapters such as "*Fa-Yi*," "*Ci Guo*," "*Jie Yong*," "*Tian Zhi*," "*Fei Ru*," and "City Defense"), demonstrating familiarity with Baigong prac-

tices, while other pre-Qin philosophers rarely mention the Baigong.

Mohism practiced the way of Yu. The Mozi "Universal Love" chapter states: "To seek to promote the benefit of the world and eliminate its harm—this is the universal love of Yu. Although what Mozi calls universal love is sought from Yu" (Sun, 2021), explicitly tracing the Mohist mission to the way of Yu. The Huainanzi states that Mohism "turned its back on Zhou ways and adopted Xia policies," considering Mohism as inheriting the tradition of Yu the Great. The *Zhuangzi* "Tianxia" chapter, in its description of later Mohists, notes that "without the way of Yu, one is insufficient to be called a Mohist" (Chen, 1983), also demonstrating Mohists' transmission of Yu's way. The *Zhuangzi* "Tianxia" considers Mohist thought of "self-rectification through the ink line, to prepare for the emergencies of the world" as inherited from "the ancient way that existed in this" (Chen, 1983). Through the preceding analysis, the way of Yu clearly also possesses the attribute of the "ink line."

The Mohist "Juzi" culture also reflects the "craftsman-compass-square" origins. After Mozi, Mohist leaders were called "Juzi," and the character "巨" graphically symbolizes a person holding a T-shaped carpenter's square (ju) (Shuowen Jiezi: "巨, the compass and square. From 工, like holding it in the hand") (Ji, 2025b; Zhang, 2022). Such a cultural manifestation explicitly demonstrates the internal connection between Yu, Mozi, and the craftsmen (gong), and its relation to *Fa-Yi*.

In the history of Fa-Yi thought, a clear "Yu the Great–Baigong–Mozi" developmental lineage emerged (Xu, 1998; Gao, 2022). In this transmission chain spanning approximately two thousand years, we can readily discern that the engineering thought of ancient Chinese artisans traversed a path of "large-scale testing practice → engineering standardization and normalization, transmission institutionalization, *Fa-Yi* popularization → *Fa-Yi* philosophical theory."

Taken together, the above analysis provides an answer to the PreNeedham Question: Mohist rationality did not emerge from nowhere, but was the theoretical sublimation of the "Yu the Great—Baigong—Mozi" *Fa-Yi* tradition. This tradition was neither based on Greek-style agora debate, nor dependent on the impetus of the Reformation, but originated from the deepening recognition of the objectivity of *Fa-Yi* in the process of craftsman practice.

ANCIENT ENGINEERING EDUCATIONAL MODELS BASED ON FA-YI THOUGHT

Fa-Yi thought played an important role in ancient engineering education, forming multiple forms. The following is a brief overview and discussion.

The First Form: Self-Rectification Through the Ink Line, Imitation Surpassing Oneself

The Mozi·*Fa-Yi* states: "The skillful can hit the mark; the unskillful, though unable to hit it, imitate and follow in their work, and still surpass themselves." (Sun, 2021) The *Zhuangzi* "Tianxia" evaluates Mohism as "self-calibrating through the ink line, to prepare for the emergencies of the world" (Chen, 1983). The two texts derive from different sources but express nearly identical ideas, which unfold on three levels:

1. Standards are defined by using instruments. The ink line is an objective measure. Once the ink line is snapped, whether something is straight or not is determined by the line itself, not by personal preference or authority. The objectivity of education is established through *Fa-Yi* instruments.
2. Deviations serve as direct learning resources for self-correction. Apprentices need not wait for the master to grade or criticize them; they can see their own errors in the process of operation and correct them immediately. The driving force for learning progress is not external reward or punishment, but one's own pursuit of perfection.
3. External standards are gradually internalized into self-regulation through repeated practice. The "self" in "self-rectification" emphasizes that the learner can improve themselves. The external standard represented by the ink line gradually becomes the internal measure of the operator through repeated processes of "imitation and following in work."

The Second Form: Every Statement Must Establish a Standard, Rooted in the Three Criteria

The *Mozi* "Fei Ming" advocates that when expressing views one must simultaneously establish testing standards, that is, "every statement must establish a standard (yan bi li yi)" (Sun, 2021). The principle that "every statement must be grounded in a standard" is intellectually consistent with "selfcalibration by the ink line" but advances further, extending from technical skill to the wider spheres of discourse, conduct, and governance.

Regarding the question of how to select testing standards, Mohism proposed the "Three Criteria method" (san biao fa): "there is that which is rooted, there is that which is traced, there is that which is applied." "Above, root it in the affairs of the ancient sage kings; below, trace it in the sight and hearing of the common people; and once issued as punishments and policies, observe whether they benefit the state and the people." (Sun, 2021) These Three Criteria provide three dimensions for

Fa-Yi evaluation:

1. Root—historical precedent. *Fa-Yi* is not invented from thin air. What did the ancient sage kings do when faced with similar circumstances? This is "taking history as the standard."
2. Trace—empirical verification. Whether *Fa-Yi* is good cannot be determined by mere words. What the common people see with their eyes and hear with their ears, and what is obtained through practice, is the testing standard. This is "taking reality as the standard."
3. Apply—social benefit. Ultimately, one must see whether it can promote the benefit of the world and eliminate its harm. This is "taking benefit as the standard."

From history to practice, from operation to benefit, the three-standards method constitutes a complete evaluation system, a set of directly usable testing procedures.

The Third Form: Observing Craftsmanship, Transmitting Norms, Inquiring into Causes, Observing Appropriateness

The Jing Shang states "where the standard is the same, observe their sameness; where the standard differs, observe its appropriateness," and the Jing Shuo Shang states "the standard: taking sameness from the standard, observing craftsmanship and transmitting norms, selecting this and rejecting that, inquiring into causes and observing appropriateness" (Sun, 2021), revealing the important position of the concept of "standard" (fa) in the Mohist educational system. Here, "craft" (qiao) refers to the exquisite techniques in engineering activities, "norm" (fa) refers to the transmissible norms distilled therefrom, and "transmit" (chuan) explicitly reveals the core of educational activity—transforming individual technical experience into shared operational knowledge for dissemination or transmission. "Cause" (gu) is defined in the Jing Shuo Shang as "that which is obtained and then becomes complete," that is, the causal mechanism by which things are formed (Sun, 2021). "Inquiring into causes" means pursuing the essential causes of things, and "observing appropriateness" means examining the suitability of things to their circumstances.

In this text, Mohism presents a "cause-inquiry and appropriateness-observation" type of *Fa-Yi* educational model—this model does not lie in abstractly lecturing on laws and rules, but in enabling learners to progress from mastering specific skills to understanding universal principles, and to flexibly select and apply them according to specific engineering problems, through the complete chain of observing engineering examples (qiao), distilling operational norms (fa), pursuing causal mechanisms (gu), and adapting to specific circumstances (yi).

In the third form, there exists no discontinuity between technology and science (Wu, 2015)—engineering must consider human needs and complex environments, hence "observing appropriateness"; engineering must employ techniques, hence "observing craftsmanship"; through "observing craftsmanship" one "transmits norms," to master transmissible and generalizable standards; if sameness is found in the norms, one must "observe their sameness," to induce and summarize laws; if differences are found in the norms, one must "observe its appropriateness," to distill applicability. It can be seen that in educational activities, Mohism advocated combining technical methods with engineering practice to pursue causal laws. This is a path from technology to science. One can say that at the epistemological level, Mohism had already integrated the relationships among engineering, technology, and science.

This model finds concrete pedagogical expression in the famous "Eight Canons of Optics" in the Jing Xia/Jing Shuo Xia (Qian, 1951). Mohism does not directly present the laws of rectilinear propagation, projection, and reflection of light, but presents a set of experiments, such as the "pinhole imaging" experiment. Learners must complete the experiment and deduce natural laws from experimental phenomena in order to obtain the laws. This can be regarded as a typical case of the "transmitting norms and inquiring into causes" teaching model. Moreover, it should be noted that Mohism had the classificatory research methods of "examining categories and illuminating causes" (chalei minggu) and "proceeding by category" (yilei xing); the Mohist Canons exhibits clear categorical grouping of relevant passages on optics, mechanics, economics, society, and cognition, evidently an intentional arrangement, which can be regarded as the embryonic form of "disciplinary study" (fenke zhi xue).

Compared with the foregoing educational ideas of "self-rectification through the ink line, imitation surpassing oneself" and "every statement must establish a standard, rooted in the Three Criteria," this *Fa-Yi* educational model involves concepts such as cause, appropriateness, sameness, and difference, and is philosophically more profound in terms of engineering implications.

DISCUSSION

The above three *Fa-Yi* educational forms exhibit different transmission dependencies and output forms, as summarized in Table 1.

For the first form, as long as instruments or tools such as the ink line exist, self-education concerning "self-rectification through the ink line" may occur among artisan communities. Therefore, even though the Mohist school,

Table 1: Comparison of the Three *Fa-Yi* Educational Forms

Dimension	First Form: Self-Rectification	Second Form: Establishing Standards	Third Form: Observing Craftsmanship, Inquiring into Causes
Core Mechanism	Instrument feedback → self-correction	Three-standards assessment procedure	Craft → Norm → Cause → Appropriateness complete chain
Educational Output	Operational skills (craft)	Speech/decision standards	Scientific laws + situational wisdom
Transmission Dependency	Tools (ink line, etc.)	School culture (partially compatible with Confucianism)	Complete school-based educational system
After Mohism's Decline	Continues in non-self-conscious forms (used daily by the people without their awareness)	Partial concepts absorbed and transformed by Confucianism	Complete procedure utterly severed
Ability to Pursue "Causes"	Limited	Moderate (through empirical "tracing")	Strong (dedicated "inquiring into causes" link)

Note: *The dimension labels in this table are aligned with the terminology established in Chapter 3 of the main text:1. Core Mechanism: Corresponds to the operational logic of each form as analyzed in Sections 3.1–3.3.2. Educational Output: Corresponds to the primary learning outcome produced by each form.3. Transmission Dependency: Corresponds to the material or institutional conditions required for each form's continuity (Section 3.4).4. After Mohism's Decline: Corresponds to the post-Mohist fate of each form as discussed in Section 3.4.5. Ability to Pursue "Causes": Corresponds to each form's epistemological capability for causal inquiry into gu (Chinese: 原因 / 理由); the distinction between causal-explanatory (cause) and epistemological (reason/grounds) senses of gu is maintained throughout.*

which championed *Fa-Yi* thought, faded from the historical stage, this form of education still persists. However, this educational method can point toward "craft" but cannot directly lead to the investigation of "causes," and its function in promoting the artisan community's exploration of scientific laws is relatively limited.

The core of the second form is "revering history," "being close to the people," and benefiting the people, along with the related self-reflection. In Confucian culture, there are intellectual resources such as "taking history as a mirror, one can know the rise and fall of states," "the people are the foundation of the state, when the foundation is solid the state is tranquil," and "cultivating oneself, regulating the family, governing the state, bringing peace to the world," which possess a certain affinity with the "root," "trace," and "apply" of the three-standards method. This means that even though Mohism as a school became extinct, certain elements of the second form—"revering history" and "being close to the people"—could still find continued space within the Confucian educational tradition. However, the Three Criteria Method as a complete assessment procedure—which demands that claims be tested against history, empirical evidence, and social benefit—ceased to be consciously taught and applied as an integrated system after Mohism declined.

The third form contains the "inquiring into causes" link, which is more conducive to the exploration of scientific laws. In the Mohist Canons context, passages related to "inquiring into causes" involve systems theory, experimental methods (Ji, 2025a), logic, and taxonomy, and the Mohist "four doubts" and "seven knowledges" epistemological tools are also related thereto (Ji, 2023a; Ji, 2023b), which can explain why Mohism was able to make many discoveries and inventions beyond its time. Yet from the decline of Mohism to the European Industrial Revolution, China never again saw a craftsman-type school consciously practicing "observing craftsmanship—transmitting norms—inquiring into causes." In engineering texts such as the Qin Laws·Artisan Laws and the Yingzao Fashi, there are traces of "observing craftsmanship—transmitting norms," but demands for "inquiring into causes" are rare (Liu, 2012).

The comparison of the three forms reveals a deep-seated problem: the first form depends on tools (the ink line); where the tools exist, education exists, but it points more toward "craft" and is difficult to lead toward "causes." The second form depends on school culture (systematic training in the three-standards method); it possesses affinity with Confucianism, but the integrity of the procedure is easily lost. The third form depends on the most complete school-based educational system (observing craftsmanship—transmitting norms—inquiring into causes—observing appropriateness), but its transmission chain is also the most fragile. After the decline of Mohism, the tool-based transmission of the first form continued in non-self-conscious ways (used daily by the people without their awareness); partial concepts of the second form were absorbed and transformed by Confucianism; the complete procedure of the third form was utterly severed. Needham's remark that "the Taoist insight into Nature and the Mohist passion for logic never combined" (Needham, 1990), understood from the perspective of educational history, truly describes the loss not of certain individual technologies, but of a complete methodological procedure for systematically pursuing causal laws through the investigation of engineering practice, along with its pedagogical methods.

EARLY GERMINATION OF FA-YI

THOUGHT

The gnomon shadow measurement system in Yu the Great's era was already complex and sophisticated. Given the limited knowledge capacity of prehistoric humans, such a system could not have appeared abruptly. This raises the question: how did it evolve in its early stages? The archaeological record offers the only available answer.

The evidence assembled below is presented not as a comprehensive survey of material culture, but as **background and premise**. Its function is to demonstrate **existence**: to show that the operational foundations of *Fa-Yi* rationality were grounded in millennia of practical experience—not out of nothing. How these practices evolved into philosophical theory is addressed in Sections 2 and 3. Accordingly, the following examples are organized by type and function, without exhaustive sitebysite analysis:

1. The Shangshan site in Zhejiang (ca. 11,000–9,000 BP) shows that early residents observed and recorded solar azimuth changes using sun patterns and sunrisesunset motifs on painted pottery (Jiang, 2021).
2. At the Jiahu site in Henan (ca. 9,000–7,500 BP), the tuning holes of bone flutes and pitchpipe tuning devices indicate the emergence of musical temperament and the beginnings of standardized practice (Huang, 1989).
3. The Dongmentou site in Zigui, Hubei (ca. 8,000 BP) yielded a stone tablet (tablet gnomon) hailed as "the oldest shadow-measuring instrument yet seen." Archaeologist Feng Shi argues that its carved sun and human figures depict ancient people using their bodies to measure shadows, marking the origin of gnomon shadow measurement (Feng, 2023).
4. Unearthed at the Dadiwan site in Qin'an, Gansu (ca. 8,000–4,800 BP), anomalous pottery vessels exhibit definite volumetric proportional relationships, regarded in the History of Chinese Weights and Measures as possibly the earliest metrological instruments (Qiu et al., 2001).
5. The incised bone plaque unearthed at the Sanxingcun site in Jintan, Jiangsu (ca. 6,500–5,500 BP) features concentric circles drilled around a central perforation, arranged in one to two rings, combined with symmetrical dot-pattern composition, demonstrating a high degree of geometric regularity and indicating that artisans of the time had already mastered stable circle-drawing and positioning techniques (Li, 2025).
6. The multi-section cong tubes of jade unearthed at the Liangzhu site in Zhejiang (ca. 5,300 BP) are finely crafted, with clear proportional division and standard square morphology. Feng Shi considers the form of the jade cong related to the circle-square diagram in the Zhoubi Suanjing, demonstrating the ancient people's mastery of square-inscribed-circle techniques (Feng, 2006).
7. From the Yangshao and Longshan cultures to the Xia period (ca. 7,000–4,000 BP), the evolution of architectural orientation from random to regular, and even to the planning concept of the central axis, highlights the demand for measurement capabilities and geometric methods concerning distance, rectangle, perpendicularity, and horizontality (Zhang, 2020).
8. The stone boundary markers of the Niuheliang sacrificial altar site in Inner Mongolia (ca. 5,000 BP) demarcate three circular rings with diameters of 11 meters, 15.6 meters, and 22 meters, exhibiting a multiple relationship of the square root of 2. Archaeologist Feng Shi considers this the embryonic form of the diameter multiple relationship of the triple circular rings in later heaven-worship architecture (Feng, 1993).
9. The Taosi site in Linfen, Shanxi (ca. 4,300 BP) yielded gnomon remains. Scholars such as He Nu consider them to correspond with the pole-erection shadow-measurement methods recorded in texts such as the Zhoubi Suanjing (He, 2009). This indicates that later concepts of geometric mathematics had relatively early origins.
10. The Shang dynasty (ca. 3,600–3,000 BP) saw the emergence of graduated decimal bone rulers, regular city sites, and vehicle, boat, and agricultural implements. Oracle bone inscriptions contain not only records of land measurement but also numeral records ranging from one to ten thousand, with the mature length system and greatly expanded scope of quantitative statistics (Han, 2010; Tang, 2017).
11. The Bamboo Slip Calculation Table from Tsinghua University provides empirical evidence that by the Warring States period, China was already capable of performing multiplication, division, and square-root operations (Li & Feng, 2014). Scholars such as Zou Dahai consider that the geometric-mathematical concepts in the Mohist Canons may have been merely introductory foundational knowledge of this period, at a foundational rather than peak level (Zou, 2010).

The materials cited above, though distributed across different periods and regions, point to a single trajectory: over thousands of years before writing, artisans developed basic operational concepts through craft production. These experiences, transmitted and gradually standardized within the Baigong system, were eventually

distilled by the Mohists into the philosophy of Fa-Yi. The integration of technical operation and standardized cognition was thus a natural feature of artisan practice across nearly eight millennia of prehistory. These materials further confirm that ancient Chinese rationality was not merely a product of abstract philosophical speculation—operational rationality rooted in material practice stands as one of the sources of human rationality.

MODERN INFLUENCE AND CONTEMPORARY IMPLICATIONS OF FA-YI THOUGHT

Historical Legacy

The Mohist school gradually declined after the Qin and Han dynasties, but *Fa-Yi* thought had already been deeply integrated into the fabric of Chinese culture. From an etymological perspective, instruments and concepts related to ancient engineering *Fa-Yi*—gui (compass), ju (square), fa (standard), yi (norm), zhun (level), sheng (string), du (degree), liang (measure), heng (balance), fan (model), lü (law), and ze (rule)—have given rise to modern Chinese vocabulary such as "law," "rule," "norm," "criterion," "standard," "legal," "scale," "measurement," "assessment," and "evaluation." These remain fundamental terms for expressing "correctness" and "objectivity" in modern Chinese, functioning across science, technology, engineering, and society (Yang, 1996). The *Fa-Yi* rationality originating from the "Yu the Great—the Baigong—Mozi" lineage has thus continued in non-self-conscious ways, persistently shaping Chinese cognitive patterns and judgment habits—"used daily by the people without their awareness."

Contemporary Implications

Modern engineering education has long grappled with a foundational question: should it be grounded in scientific epistemology, or does it need an independent epistemological foundation? *Fa-Yi* rationality provides a reference from historical practice—in Mohist educational activities, "observing craftsmanship and transmitting norms" and "inquiring into causes and observing appropriateness" are not two separate links, but different levels of the same engineering cognition process: at the operational level, pursuing "how to do it"; at the theoretical level, pursuing "why to do it this way." This unique epistemological structure, originating from long-term engineering practice, provides Eastern intellectual resources for contemporary engineering education.

The following discussion offers a brief mapping of the three *Fa-Yi* models onto contemporary learning theories. This is presented as a **derived implication** rather than a systematic comparative study in pedagogy.

(1) "Self-Rectification Through the Ink Line" and Self-Regulated Learning: *Fa-Yi*-Augmented Self-Regulated Learning (Fa-Srl)

The core of this model lies in external instruments providing objective, immediate feedback, enabling learners to detect deviations and correct themselves without external evaluation. Structurally, this parallels the "self-monitoring" and "self-reaction" phases in Zimmerman's Self-Regulated Learning (SRL) theory—both emphasize learner autonomy and feedback-driven correction (Zimmerman, 2002). However, a key difference exists: Zimmerman's theory focuses on internal metacognitive processes, while the "ink line" model draws feedback directly from external material tools. In engineering contexts, this gap is significant. The Mohist model thus offers a necessary augmentation of SRL in engineering education, which we term ***Fa-Yi*-Augmented Self-Regulated Learning (FA-SRL)**. In modern practice, this principle can be implemented through digital twins, sensor-based quality inspection, and BIM clash detection, enabling apprentices to form an autonomous cycle of "execution—comparison—correction".

(2) The "Three Standards" Method and Argumentation Evaluation: *Fa-Yi* Three-Standards Argumentation Evaluation (FA-TSAE)

The Three Standards method (rooted in history, traced in empirical evidence, applied to social benefit) functions as a procedure for testing claims and decisions. Its principle is that any proposition must be tested against historical precedent, empirical verification, and benefit assessment. This is structurally comparable to Critical Thinking and Argumentation Evaluation frameworks in contemporary education. In engineering education, this can be operationalized as ***Fa-Yi* Three-Standards Argumentation Evaluation (FA-TSAE)**—a method for training evidence-based decision-making: learners facing a technical problem sequentially consult historical cases (root), conduct on-site measurements (trace), and evaluate cost, safety, and sustainability (benefit). This transforms "following orders" into "reflective evaluation." Its multi-dimensional structure also bears similarity to Stufflebeam's CIPP model (Context-Input-Process-Product) (Stufflebeam, 1983).

(3) "Observing Craftsmanship, Transmitting Norms, Inquiring into Causes, Assessing Appropriateness" and Cognitive Apprenticeship: *Fa-Yi* Cause-Inquiry Cognitive Apprenticeship (FA-CICA)

This model comprises a complete learning chain from observing demonstration (observing craftsmanship) to knowledge codification (transmitting norms), from causal inquiry (inquiring into causes) to contextual

application (assessing appropriateness). At the procedural level, it aligns with the six phases of Collins et al.'s Cognitive Apprenticeship—Modeling, Coaching, Scaffolding, Articulation, Reflection, and Exploration (Collins, Brown, & Newman, 1989).

However, an important difference exists. Cognitive Apprenticeship is a pedagogical framework focused on cognitive skill acquisition. The Mohist model contains an explicit ontological commitment and an epistemological framework. Ontologically, *gu* (cause) is defined as "that by obtaining which something is completed"—the causal mechanism by which things come into being. Inquiring into *gu* is itself the core educational objective. Epistemologically, the "Seven Ways of Knowing" provides a systematic classification of cognitive processes. "Inquiring into causes" is thus not merely a phase in instruction but the overarching goal: learners must understand not only "how" but "why," and ultimately judge "how appropriately" in new contexts.

We characterize this as ***Fa-Yi* Cause-Inquiry Cognitive Apprenticeship (FA-CICA)**—an augmentation of Cognitive Apprenticeship at both ontological and epistemological levels.

The three correspondences each emphasize a different dimension: external tool feedback augmenting SRL (FA-SRL); multi-dimensional argumentation evaluation (FA-TSAE); and process-sharing with enriched theoretical foundations (FA-CICA). Together, they point to a central insight: Mohist *Fa-Yi* rationality developed a methodology of education rooted in engineering practice over two millennia ago, and its structural features offer valuable dialogue with contemporary learning theories. A systematic pedagogical elaboration, however, lies beyond the historical scope of this paper and awaits future research. The two rational traditions—Western and Eastern—can complement rather than substitute for each other in contemporary engineering education: the Western tradition provides analytical tools, while the *Fa-Yi* tradition reminds us that the epistemological foundation of engineering education should always return to operational practice itself.

CONCLUSION

This paper has proposed the "Pre-Needham Question," shifting the focus of inquiry from "why modern science did not develop in China" to "where the rational tradition that sustained ancient China's long-leading science and technology originated." Through a dualevidence approach combining textual research and archaeological findings, the study has established three core historical findings. First, the Eastern rationality system represented by Mohism did not emerge from abstract philosophical speculation, but originated from the operational procedures of artisans that could be transmitted across generations. A clear intellectual lineage—Yu the Great – the Baigong artisans – Mozi—can be traced across approximately two millennia. The evolutionary path of this tradition followed a coherent trajectory: largescale engineering practice → artisan standardization norms → *Fa-Yi* philosophical theory → engineering educational models. Second, Mohist Fa-Yi rationality gave rise to three distinct forms of engineering education: (1) "selfrectification through the ink line" as a toolbased selfcorrection model; (2) the "Three Criteria" method (san biao fa) as an assessmentprocedure model; and (3) "observing craftsmanship, transmitting norms, inquiring into causes, and assessing appropriateness" as a causalinquiry model. These three forms exhibited fundamentally different trajectories of transmission: the first, dependent on tools, continued in nonselfconscious ways to the present day but remained confined to the operational level; the second, though sharing conceptual affinity with Confucian culture, lost its methodological integrity as the Three Criteria procedure ceased to be transmitted as a complete assessment system; the third, dependent on the most complete schoolbased educational system, was utterly severed following the decline of Mohism. This differential transmission precisely responds to the "technology without science" discontinuity thesis: what was lost was not individual technologies, but a complete methodological procedure for systematically pursuing causal laws through the investigation of engineering practice, along with its pedagogical methods. Third, the epistemological significance of *Fa-Yi* rationality lies in its demonstration that engineering practice itself can generate knowledge, rather than merely receiving guidance from scientific theory. This tradition offers an alternative historical pathway for understanding the relationship between "technology" and "science" in ancient China—one that does not conform to the Western Scientific Revolution paradigm. It also constitutes a historical precedent for an independent epistemological foundation for engineering education. The historical investigation of this paper concludes with the decline of Mohism. The implicit continuity of *Fa-Yi* rationality in later periods—as reflected in the etymological sedimentation of *Fa-Yi* vocabulary in modern Chinese and its persistent shaping of Chinese cognitive habits—has been briefly noted in Section 5.1. Its systematic implications for contemporary engineering pedagogy, including the three correspondences with modern learning theories outlined in Section 5.2, await further research. In the age of artificial intelligence, when AI systems can perform "observing craftsmanship" and "transmitting norms" with precision far exceeding human capability, the core strengths of *Fa-Yi* rationality—objective standardbased evaluation logic, the unified structure of concept–instrument–outcome, and the methodological commitment to deriving causal

laws from practice—may find renewed relevance. For human engineers, the irreplaceable core competence will increasingly lie in "inquiring into causes": pursuing causal laws, assessing appropriateness across complex contexts, and making ethical decisions. The methodological framework that grew out of engineering practice in Mohism more than two millennia ago points precisely to the question that engineering education most needs to answer in the AI era: in a context where technical capabilities can be massively replaced by machines, in an age when humans and artificial intelligence both participate deeply in engineering activities, what is the fundamental *Fa-Yi* of engineering and engineering education?

DECLARATIONS

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The author has no conflicts of interest to declare.

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This study used artificial intelligence (AI) only to assist with the verification of English-language materials and the proofreading of English translations.

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