Science and technology in ancient Sri Lanka

by Kamalika Pieris

In ancient times, the phenomena that aroused the most interest were those that could be observed. This included the stars, the moon and the ocean tides. The Sinhalese knew about the effect of the moon on ocean tides. Mahavamsa carries a reference to this. Astronomy has everywhere been the first science to emerge. The Sinhalese knew astronomy. The term '*ganaka*' was used in ancient times to denote astronomer, astrologer as well as accountant, suggesting that these disciplines were related

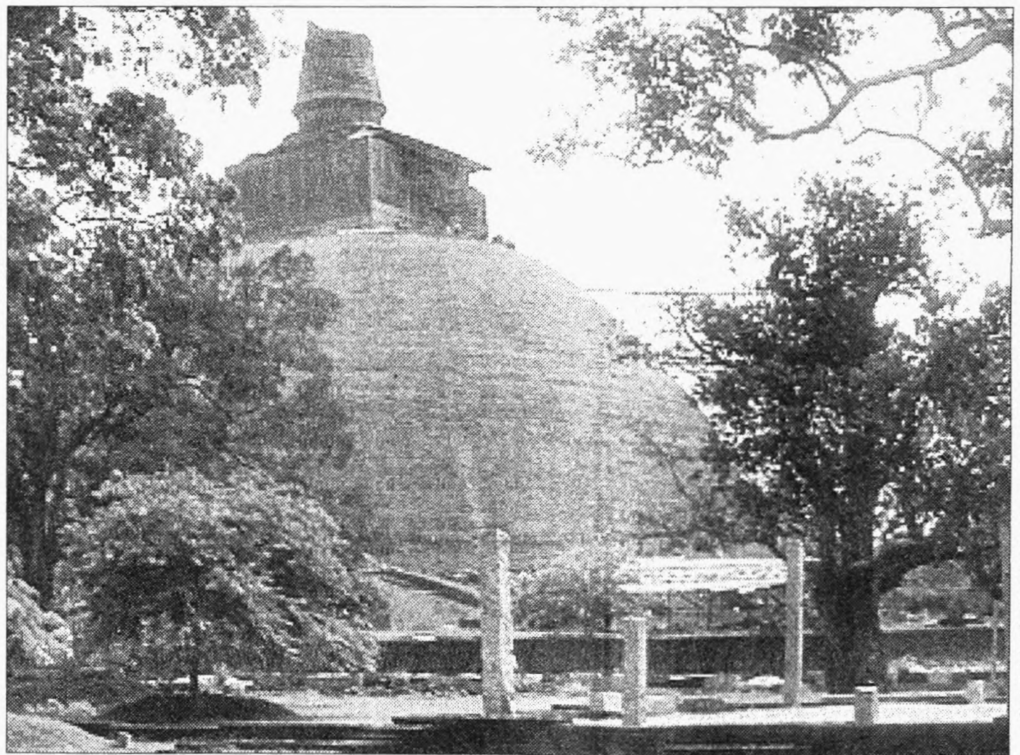
Pliny writing about the Sinhalese ambassadors who went to the court of Rome in the time of Claudius, (41-54 AD) said that they had made observations on the night sky in Rome. They had remarked on the difference in the position of the stars when seen in Sri Lanka and Rome, and spoke of constellations that were not visible in either place. They specially referred to the position of the star Canopus that was used at that time in Rome to calculate the circumference of the earth.

The notebooks of the monk Vibhutichandra, who lived in Tibet, showed that the Sinhalese tradition of astronomy was held in high regard. The date of this work is not given. The Indian work Suriya siddhanta dated to approximately 4th century AD referred to the exchange of information between astronomers in Sri Lanka and other parts of South Asia.

This knowledge was put to practical use in the built environment. The buildings at Anuradhapura are positioned east-west and north-south 'without an iota of difference'. At Sigiriya, the eastern and western precincts of the royal complex have been laid out in a precise square module with the north-south and east-west axis meeting at the centre, of the palace on the summit.

The ancient Sinhalese were skilled builders. They built elaborate, multi-storeyed structures with retaining walls and flights of steps. One stairway had hundred steps. Lohamahapaya, built in the 2nd century BC was 9 stories high and 100 cubits long on each side. It was covered with bronze files and protected by lightening conductors made of amber and tourmaline. Badda seema pasada built in 12th century at Alahana, pirivena, Polonnaruwa, was a 12-storey building.

The religious buildings were also of mammoth scale. Jetavana stupa built in the third century AD was the tallest brick building in the world at that time. It was about 40 storeys high. It was second in size only to the Pyramids. It was larger than the Parthenon in Athens, Pantheon in Rome or St. Sophia in Costantinople. Ruvanvelisaya was 298 feet broad and about 300 feet high. Abhayagiri and the uposathagara at Jetawana were also very large. Ashley de Vos thinks that the Anuradhapura stupas may be the first prefabricated buildings in the world. Certain sections, such as the entrance and the moonstone were prepared close by and then fitted together. He said that the workmanship was so precise as to be almost unbelievable. (*SLIA 5th Public Forum 1988 p 62.*)



Jetavana stupa built in the third century AD was the tallest brick building in the world

The ancient engineers knew how to build. They knew about load, stress, height, span, stability. They were able to construct arches, vaults, and domes. They used framed as well as load bearing and earth compacted structures. For Ruvanvelisaya, the earth was compacted using elephants whose feet were bound with leather.

In recent times, when the Jetavana stupa was being renovated, structural engineers were called in. They found that the existing shape was the most suitable for that particular mix of brick and clay mortar and that it would give the best strength. Metal was used in construction. Dutugemunu used metal tiles for the roof cladding in Lohamahapaya. Anuradhapura stupas used iron for the foundation. Iron bands were used on bridges. There were metal frames in the Maduru oya sluice.

Large-scale irrigation schemes came into existence in Sri Lanka several centuries earlier than in South India where comparable schemes can be traced only to late 3rd or early 4th century AD.

It is likely that the construction of anicuts and canals was first tried out in the wet zone where the early settlements were, and then used in the dry zone. Water was used and re-used many times in the ancient system. Streams were also included. Canals picked up water from streams. Complex and intricate irrigation systems were developed in almost all the river basins in the dry zone. As many rivers and streams as possible were incorporated into one system. These irrigation schemes are today viewed as water and soil conservation systems, not mere water distributing systems. The new idea regarding small tanks is that its main function was to recharge the ground water and make the environment hospitable.

These irrigation systems had several remarkable features. The British declared that the Sinhalese were the inventors of the cistern sluice (biso kotuwa). Excavations in 1902 had exposed the biso kotuwa at Giritale. The biso kotuwa had appeared in the ancient sluices by 2 century AD. Europe installed valvepits in their reservoirs only in the 19th century. The massive stone masonry spill of Kalawewa, is considered outstanding. This spill consisted of hammered granite, protected with heavy pitching, excellently dressed and mortised at the crest. It was 216 feet wide and 170 feet long. The Yoda ela, which went from Kalawewa to Anuradhapura, was a tremendous engineering feat marvelled at by modem engineers.

Minneriya, constructed in 3rd century AD was the largest tank of its time. There was no reservoir in South Asia to equal that of Minneriya. (R. A. L. H. Gunawardana Sunday Observer. 24.10.1999 p 32.) It had a circumference of 15 miles. It covered 39 square kilometres and had a capacity of 87 million cubic maters of water, capable of irrigating more than 4450 hectares. Its embankment was only one kilometre long. It was still functioning when the British discovered it.

Most of the irrigation schemes were on undulating land and the canals took serpentine routes. Long canals such as the Jaya ganga and Elahara required accurate measuring instruments to achieve the minimum gradient. Yoda ela and Minipe ela had a gradient of 6 inches to a mile. R. L. Brohier remarked that such gradients would need very precise instruments even today. But even with modem instruments, it would not be possible to improve on the work of the ancient engineers. They had been so exact.

Other elements in the irrigation works merit comment. The art of raising water by machinery was practised. (*Brohier. Pt 1. 1934.p 3*) The ancient reservoirs were provided with adequate spills. These 'galwanas' or rock spills were usually located on natural rock outcrops, designed to enable the water to get away rapidly. Where this was not possible, artificial spills were provided.

These were built into the bunds at intervals, some of them were 50 feet wide with, solid wing walls. These permitted an over flow and were distributed at points where the water may rise too high for the safety of the bund.

The anicuts (*amunas*) were made of stone blocks, several courses wide and high, sometimes weighing close to half a tonne. They were articulated together with the use of lipping to form a wall across the river. Water resistant lime and quartz-pebble concrete was used. The Sinhalese excelled in placing these anicuts. An anicut was placed at Kalinga, where the Mahaweli flowed over granite, in a series of rapids, making the water fall 12 feet or more. Water was diverted into two channels, one on each bank.

It was noted that Kuda Wilachchiya tank had two remarkable features. It has a bank set above a bank both pitched in stone with a unique sluice, the door of which was hewn rock set in grooves so that the door could be slid up and down.

British engineers said that great engineering skill has been shown at Elahera in preparing the rock to receive the foundations of the large stone bund. There were trenches and holes for holding masonry and stone pillars. Safe guards were constructed to prevent breaches when the canal collected water from the streams that entered it. This was done through stone foundations and stone pitching which were still there in the 1930s.

There was water management elsewhere too. There were baths and ponds in the major cities such as Anuradhapura and Polonnaruwa. The elephant pond, or *eth pokuna*, in Abhayagiri, had a depth of about 10 metres, and was about five times the size of an Olympic pool. Clean water was delivered through underground conduits made of stone or terra cotta. There were outlets to drain the water. Sigiriya had a pond divided into four quadrants, each with a canal connected to underground water conduits at varying depths. Some of the conduits at Sigiriya and 'eth pokuna' function to this day. There were fountains at Sigiriya fed by water conduits placed at different levels. These fountains still work in the rainy season.

There is evidence of sound scientific principles in the construction of sanitary facilities. The ancient monasteries and palaces had toilet complexes consisting of urinals and sanitary closets. At Abhayagiri, each residential unit had a separate complex. The drainage system was similar to modem concepts in sanitation. The lavatories were connected by stone conduits to septic tanks outside the buildings. The wastewater from the basin was drained by an underground conduit to a covered square soakage pit, situated within the walled enclosure.

In the palace at Panduwasnuwara, a stone conduit drained the water form the toilet floor to a circular brick built pit lined with rings of terra cotta. A stone stab had sealed this seven-foot deep pit. At Alahana, there is a toilet complex in which one room was used for bathing and the other as a toilet. Two soakage pits, built of bricks were found behind each of these two rooms. Bricks the interior of the pit were laid with wide spaces filled with plaster, an arrangement that would have facilitated soakage of water.

In some instances, drainage water was led into an earthenware pot or a series of pots placed one above the other, behind the urinal stone. The pot below was larger than the one above, and there was a hole in the bottom of each pot. These were filled with charcoal, ash, or sand to ensure graded filtration.

There was provision for baths, some times equipped for hot water. The hot water bath at Mihintale hospital had an underground duct for draining away the waste water. The granite-paved floor of the immersion therapy room at Alahana has been sloped toward the north and water that led from it had been diverted into a drain.

(Continued tomorrow)

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There was a substantial metal industry using technology that was way ahead of this tune. There was a gold industry. Modern geological surveys have confirmed the presence of gold in many of the villages that have names beginning with 'ran'. Copper was mined and processed at Seruwila and a brick built furnace for copper smelting was found in the citadel at Anuradhapura. Bronze foundries using clay furnaces lined with mica and graphite, were excavated at Abhayagiri together with moulds for casting statues, coins, and crucibles.

In 1847, the British rulers observed that iron ore occurred in large masses and veins in Sri Lanka. One vein extended for a distance of fifteen miles. They said "The quality is singularly fine, it is easily smelted and so pure when reduced as to resemble silver. Converted to steel, it cuts like diamond." Samples sent to London had 68.7% and 79.5% of ferric oxide, which were equivalent to 48% and 55% of metallic iron.

The iron industry in Sri Lanka dates from about 2 century BC. This is a particularly early period for iron production of this scale and quality. The iron smelting 'factories' found at Sigiriya indicated industrial level production for use beyond the Sigiriya-Dambulla, region. Sri Lanka had the hematite, limonite and magnetite needed for good iron. Furnaces of this period avoided magnetite, as it was difficult to process. But Sigiriya furnaces had used magnetite. These charcoal-fired furnaces were constructed so that the temperature could be controlled. Some furnaces had four or more bellows and eight nozzles for sending in the air. The bellows were made of two large inverted terracotta pots covered with animal skin.

Crucible cast steel had been manufactured in Sri Lanka several centuries before it was produced in the west. Near Samanalawewa, researchers discovered, for the first time in the world, unique wind powered iron smelting furnaces capable of producing high quality steel for large-scale production. Its process of smelting and converting steel was faster than any other recorded for ancient furnaces. The furnaces were able to produce high carbon steel even in amateur hands.

Sri Lanka had extensive clay deposits, occurring in the flood plains of the major rivers, old river channels, owitas, tank beds, and in the deep weathered zones of the crystalline rocks. These deposits were utilised in ancient times. There was a 'truly amazing' clay industry. The, characteristics of different clay varieties were known and the clays were used selectively for different purposes. The nozzles in the iron furnaces at Sigiriya were made of clay that could withstand a higher temperature than the clay used for the furnace walls. Clay was used as the binding mortar in stupas like Jetawana, Abhayagiri, and Ruwanvaliseya. Thin slurry of clay was used to keep the bricks pasted in position and the stupa was totally covered with a thick lime plaster protecting the clay body from natural elements.

Clay was used in sluices and sometimes around culverts as well. Well-tempered clay 'puddle' (kiri mati) of excellent quality was placed around masonry that was subject to water pressure. Clay was sometimes used as the main ingredient for plaster, carefully mixed with many other materials such as sand, sulphur, lime, gums, glues, resins, and fibre. Mirror wall of Sigiriya, is a fine example of good quality clay plaster. Kudramalai, had a well dated to 11 century AD, lined with perfectly circular cylinders make of baked clay placed one above the other in a stratified fashion. Sigiriya had retaining walls of brick built on rock

The bricks manufactured by the ancient Sinhalese have come in for particular praise. The crushing strength of the ancient bricks is more than the present day machine made bricks. The bricks used for the Maduru oya sluice, dated sixth century AD, have been exceptionally strong. They could take a load of at high as 2077 pounds per square inch or 385 kilograms per square centimetre. It was not the usual type of clay and the bricks were probably fired at exceptionally high temperatures. Such sophisticated kilns were not common in this period. The bricks used for the Jetavana stupa consisted of 60% of silky sand and 40% of clay. They had had been fired very well and could withstand very high heat. The bonding material for the bricks was superb. Not even the point of a penknife could be inserted between two bricks. There is no mortar joint, so the brick shape remained as it was. The mortar even today is in perfect condition. This skill is now lost.

Lime was used as a hardener for mortars and plaster. Shells, corals and dolomite limestone have been used for burning lime. In the Polonnaruwa period, they had three methods for hardening slaked lime. By exposing into atmosphere, (calcium carbonate) by mixing with burnt brick powder, (silicate of carbon) and by mixing with milk (calcium carbonate). The lime concrete used in the anicuts was analysed by the British in 1898. The cement was of superior quality. It had 7.1% silicate of lime, while a sample of 3rd century Roman mortar yielded only 2.5% The high content of silica in the mortar indicated that the ancients knew that the addition of silica to lime gave it the ability to withstand the action of water.

Stone was an important building material. Stones had to be quarried, dressed, transported and set. They were cut out by means of wedges and thereafter chiselled. Well packed, dressed rubble retaining walls built in the fifth century are still holding the earth embankments at Sigiriya.

Lohamahapaya had 1600 stone columns that supported a multi-storey timber building. The British commented that the technique of shaping large granite pillars introduced into Britain in the 19th century, had been known in Ceylon long before that.

A stone bridge found near Kala oya in 1826 was built of stones 8 to 14 feet in length, laid in rectangular lines, some jointed to one another, each course receding from the one underneath, giving additional strength to the bridge. Eth pokuna was constructed out of large blocks of stone. The Kalawewa spill was formed of hammered granite, The anicut across the Mahaweli at Kalinga used massive, square hewn blocks of stone, weighing two or three tons. The outer wall of the Ridibandi ela darn on the Daduru oya constructed by Parakrama bahu 1, was built with stone blocks which are so intricately fitted that the joins are only a quarter of an inch wide, while its inner core was formed of undressed rubble laid in lime concrete. The sluices were invariably of square cut stones. At Sorabora wewa, they used soft rock to create the two sluices.

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Construction of large reservoirs required the handling of huge stone blocks weighing up to ten tons. At Urusita wewa, off Ridiyagama, the blocks of dressed stone were so large that no modem implements could lift them. For the embankment at Padaviya, about 600, 000 cubic yards of earth had been brought to the construction site. The movement of colossal quantities of earth, over appreciable distances would have called for the development of sufficient earth moving machinery, probably drawn by elephants.

Our soil is one of the hardest in the world. Our granite, particularly gneiss, is also hard and difficult. Even our timber is hard. As a result, iron and steel tools were developed in Sri Lanka a thousand years ahead of the west. The drip ledges and inscriptions on caves confirm that the ancient engineers had tools of superior steel. By 3rd century BC, the Sinhalese were using the fixed drill and lathe as well. The ancient technologies were labour intensive.***

The ancient engineers knew the topography, patterns, and soil properties of the island. There would also have been a system of measuring heights and distances. The Jaya ganga was planned because the ancient engineers knew what the levels at Kalavava and Anuradhapura were and that it was feasible to think of diverting water from the Kala oya to Anuradhapura. Minipe ela turned the waters of the Mahaweli at a bend in the river where the water entered a narrow channel.

Brohier, himself a surveyor, stated that the ancient engineers were highly skilled at surveying. They were able to accurately work out heights and distances and were able to determine even small differences in elevation. They also knew levelling. One method may have been to use two clay pots separated by a rod. Level surfaces were ascertained by filling this with water. Inscriptions indicate that there was some sort of surveying organisation.

Brohier is definite that the ancient irrigation engineers had worked according to design. He said "They planned beforehand. It is unlikely that work was started before determining heights and distances. Judging from the account of the construction of Loha maha pasada, in Mahavamsa, plan drawing was practised by second century BC." Nimal de Silva observed that the perfect linear arrangements seen in the ancient cities showed that engineering plans had been prepared.

Aelian de Silva has pointed out that the ancient engineering feats were done by thinking Sinhala. He has given examples of Sinhala, terms still in use in the irrigation technology. Daily News. 6.10.99 p 12) the language of science and technology in ancient Sri Lanka was Sinhala.

The calculations made by the ancient irrigation engineers were found to match modem calculations. The Kalawewa spillway meets the modem criteria for a spillway in all respects. The sluice barrel at Gantale increased from the up stream end to the down stream end by a factor of seven This agreed exactly with modem criteria. Modem sluices and anicuts ended up exactly where the ancient sluices and anicuts were.

This happened at Urusita wewa sluice near Ridiyagama, in the 1960s and Maduru oya in the 1970s. Urusita and Maduru sluices were dated to 5th and 6th centuries, respectively. Modem anicuts and modem headworks use the same ancient canals.

Modem engineers have agreed with ancient solutions. Kirindi oya dam was built at an oblique angle of nearly 45 degrees, instead of going across by the shortest possible route. It has now been found that this greatly increased discharging power and the ability to take shocks.

At Maduru oya, the brickwork above each conduit is in the forms of a corbelled arch. This was done to distribute the load to the walls on either side of the conduit, to reduce the stress. The thick brickwork in the arch acted as a second line of defence against seepage. This was the best possible solution to the materials they had to work with.

Everyday objects also have met with a favourable response. While investigating ancient traditions, C. G. Uragoda noted that the scientific principles used in the kurakkan mill are 'truly surprising for such an old object.' The radius between the mill's central pivot and handles had heen increased, reducing the workload of the operator and enabling him to use the mill for a longer period.

Some of the British engineers marvelled at the ancient irrigation schemes. They made detailed drawings of the sluices saying that they could still be used. But the official attitude was not complimentary. The British took the position that the ancient engineering achievements were based on intuitive or practical thinking.

The Sinhalese possessed profound practical knowledge of the best methods of dealing with water, said Parker in 1909. In 192 1, the headmen had pointed out that if the Tabbowa, tank filled up it would submerge part of the Puttalam Anuradhapura road. The British engineers agreed but decided that this was 'traditional knowledge' not technical.

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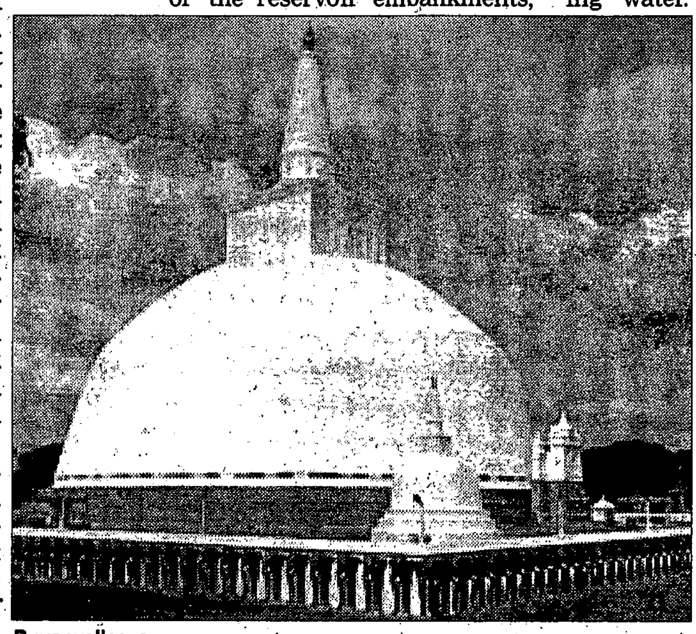
Turnour considered the Kalavava to be a badly designed work and referred to it as one of the most stupendous monuments of misapplied human labour'. Tennant said that the Yoda ela was never completed because the engineers had miscalculated the levels of reservoir and anicut. Brohier noted that it was the surveys carried out by the British in 1882 that were inaccurate. The British condemned Giants tank and Akattimurippu tank as unsuccessful engineering. Brohier saw the thinking behind it. The Giants tank and Akattimurippu tank were designed to suit a flat terrain.

A distinction has been made between the scientific knowledge of the ancient world and the 'mature science' of 16th century Europe. This is a false distinction. Science and technology began when man decided to control his environment. Each civilisation thereafter developed some sort of science. There was mathematics in Mesopotamia, irrigated agriculture in Egypt and medical systems in India and China. Pythagorean theorem was known before Pythagoras was born. Scientific ideas were transmitted from community to community, until they were picked up by the Islamic civilisation of seventh century AD and transferred to Europe from there. Knowledge relating to tropical conditions would have been dropped along the way and those relevant to Mediterranean and temperate conditions would have been retained. Europe was not the first to develop a scientific perspective. It was the last.

Ancient Sri Lanka's scientific achievements are labelled 'ethno-science'. There is nothing 'ethno' about it. It is science in the modem sense of the word. The ancient engineers had a theoretical knowledge of the phenomena they were dealing with.

They had an 'amazing' grasp of hydro-dynamics. They knew the relationship between head and pressure of water and the behaviour of liquids in closed conduits. They were evidently aware that as the water passed along the culverts the friction of the sides retarded its velocity. The Maduru oya sluice enlarged the sectional areas of the inlet and outlet culverts from their entrances to their outlets. They also had knowledge of materials. For earthen embankments, impervious clay was used within the core with semi-pervious material providing the necessary bulk, as in modem designs. Sand filter and rock toe filters had also been used. On the water face of the reservoir embankments, stone pitching called relapana had always been used as wave breakers.



Ruvanveliseya

The ancient Sinhalese knew that the chief causes of malaria were impure water and mosquitoes. They knew about the development of the human embryo and the significance of the umbilical cord. The time sequences given for the development of the embryo matches the modem view. There is no reference to dissection in the relevant text, but it seems unlikely that they could have found out all this without observation. It is even doubtful whether such knowledge could have been got by observing aborted embryos.

It is possible that ancient Sinhalese developed a system of botanical classification. The contemporary terms of madurutala, heentala, suwandatala and gastala for the plants of the Ocimum species shows a remarkable agreement with the modern botanical classification.

Pridham stated in 1849 that the Sinhalese at some time, would have had a 'complete system of botanical arrangement.' In that year, the British catalogued 416 local woods. They all had Sinhala names, hardly any English or botanical names. (J: Royal Asiatic Society, Ceylon 1849 vol. 2(9) p 135-155)

Ancient science was neither accidental nor intuitive, It was the result of experimentation. They tested out their ideas and developed methods and standards. Gunawardena, says that between 3-7 century AD, the ancient engineers were experimenting with the design of the sluices as regards he size of the cisterns, the gradient and the tapering of the outlet conduits. There has been experimentation with the use of obtuse angled elbows when releasing water. The Pavat kulam, Periyankulam and Maduru oya reservoirs illustrated such attempts to making changes. The indigenous sailing craft were developed through use and experimentation. Uragoda remarked that 'centuries of experimentation would have gone into the adoption of an acceptable formula for the size, weight and variety of timber used for the boats.'

Sri Lanka had diplomatic and trade relations with the leading nations of the time, such as Rome, Persia, India and China. This would have facilitated an exchange, of scientific information. Sanchi had a small-tank system that ran parallel to ours. The historical dates are similar. Information could have been exchanged through the Buddhist pilgrims. There may have been a transfer of technology to south India-Tamilnadu had piston sluices, not cistern sluices, therefore the cistern sluice found at Ponneri reservoir in Tanjavur district may have been influenced by Sri Lanka

Ancient Sri Lanka's industries such as glass smelting, and bead manufacture also involved science and technology. It is now suggested that carnelian found at archaeological sites was manufactured locally and not imported from Gujerat as we thought Sewwandi (chalcedony) is readily available in Ratnapura, Nivitigala, Kahawatte, Pelmadulla and can be easily converted to carnelian through heat. (M. D. P. L. Francis. SLAAS Abstracts. 2000 p 275)

This essay is based on the speeches and writings of R. L. Brohier, P. G. Cooray, J. Copper, Ashley de Vos, T. K. Nimal P de Silva, R. A. L. H. Gunawardene, Rukshan A Jayawardene, Gill Juleff., D. L. O. Mendis, C. R. Panabokke, S. Paranavitane, H. Parker, Sudarshan Seneviratne, W. I. Siriweera., Rose Solangaarachchi, C. G. Uragoda and V. E. A. Wickramanayake.

Concluded