122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12431

A Course in History of Ancient Engineering

Prof. Fabian Hadipriono Tan, The Ohio State University

Fabian Hadipriono Tan has worked in the areas of construction of infrastructures and buildings, failure assessment of buildings and bridges, construction accident investigations, forensic engineering, ancient buildings, ancient bridges, and the ancient history of science and engineering for over 40 years. The tools he uses include fault tree analysis, fuzzy logic, artificial intelligence, and virtual reality.

Adrian Hadipriono Tan, The Ohio State University

Adrian H. Tan is a graduate student at the Ohio State University. Adrian has a B.S. in Computer Science and Engineering and an M.S. in Civil Engineering from the Ohio State University. Adrian is currently working towards a Ph.D. in civil engineering and construction with a focus on computer graphics and virtual simulation in the engineering industry.

A Course in History of Ancient Engineering

Fabian H. Tan and Adrian H. Tan
Department of Civil Engineering
The Ohio State University

***Abstract* – This paper introduces the development process of a unique course, *History of Ancient Engineering*, which blends numerous areas of science and technology. Development of such a course that integrates two different major subjects, i.e., history and engineering, and the inclusion of pertinent areas such as agriculture, archeology, architecture, arts, chemistry, civil, geography, geology, hydrology, metallurgy, and physics. While the historical aspects focus on the *when, where, who*, and *what*, the engineering aspects would endeavor to solve the *why, how, made from-what*, and occasionally, *what-if* questions associated with ancient technology. The goal of this course is to increase the student's technical literacy by expanding their knowledge of how ancient engineering has shaped human history and in return, how people have shaped engineering and technology. The course is developed as a General Education Curriculum (GEC) course for the Engineering Education Innovation Center (EEIC) which includes such topics as our ancient engineers, stone tools and hafted tools, the quest for fire, ancient arts, primordial farms, early water-raising devices, the engineering of clayware, early metallurgy, simple machines, military engineering, mechanical and water engineering, and time measurement. In this paper, these topics are presented in chronological order, on weekly basis. At the end of the semester, students will furnish textual (conceptual reports), graphical (3-D images), and physical projects (manually made or 3-D printed) simulating an ancient device of their choice. Results from student and peer evaluations are consistently favorable.**

I. Introduction

How many people know that the first 3-D image in the history of humankind was created 34,000 years ago by a 'paleoengineer' on the rock ceiling of a cave in Italy? How many of us know that about 12,000 years ago, hafted tools contributed to the discovery of farming on a major scale, allowing ancient 'agricultural engineers' to invent more effective farming tools? What about 10,000 years ago, when Mesolithic 'mechanical engineers' were able to create hypermicroliths (extremely small stone tools) with skills comparable to present-day diamond cutters, except without a microscope? How about the more recent use of a *groma*, a simple surveying instrument, first invented by the Etruscans ca. 2,000 years ago, and later employed by the Roman engineers to build the first paved road in history? And do we know that the transformation of clay into celadon and porcelain constituted processes worthy of the fields of advanced chemistry and physics? These are just some of innumerable questions most of us may not even know have existed. However, as an age-old proverb once put it, "The best of the new is often the long-forgotten past," and understanding our past engineering accomplishments would be invaluable in preparing our students for the present and future.

Our engineering and technological operations and industries stemmed from prehistoric and historic engineering operations that account for 99.99% of human technological history, considering the fact that our primordial engineers created their first stone tools ca. 2.6 Ma (Mega annum, or million years) ago. To this day, most of our knowledge about engineering and technology has spanned only 250 years, i.e., since the First Industrial Revolution, ca. 1760, that represents only 0.01% of human technological history. Shouldn't we, especially our students, know what engineering processes and products were extant during the 99.99% of our technological history timeline? Shouldn't our students be given the opportunity to appreciate these embryonic technological discoveries and inventions, which became the foundation of those that fall within the 0.01% technological history timeline? One expectation of teaching the course *History of Ancient Engineering* (ENGR 2361) in the College of Engineering at The Ohio State University is to provide this very opportunity.

II. Course Contents

The History of Ancient Engineering (ENGR 2361) course includes such topics as ancient engineers, stone tools and hafted tools, ancient arts, primordial farms, early water-raising devices, water and mechanical engineering, the engineering of clayware, early metallurgy, simple machines, military engineering, and time measurement in antiquity. The best way to understand the etiology of ancient engineering is probably to travel through time. We will hop into a virtual time machine and journey back several million years, to visit the emergence of our first primordial and prehistoric "engineers" and note instances where technology became part of their livelihood. We will see how and why they did it, and the materials they used. We shall make episodic sojourns with occasional returns to the present and even visit the future. Our itinerary is presented in Table 1 below, followed by descriptions of our journey.

Table 1: Course contents

WEEK	TOPIC	Assignment/Exam Due
Week-1	**The Land Before Time**	
Week-2	**The Rock**	**HW-1**
Week-3	**The Handlers**	
Week-4	**Animal Farm**	**HW-2**
Week-5	**Best is Water of All**	
Week-6	**The Clay Masters**	**HW-3**
Week-7	**Heavy Metal**	**Midterm Exam I**
Week-8	**Historical Perspectives of Perspective**	**HW-4**
Week-9	**Simple Machines**	
Week-10	**Military Engines**	**HW-5**
Week-11	**This Old House**	
Week-12	**It's About Time: Calendrical Timeline**	**HW-6**
Week-13	**It's About Time: Horological and Atomic Timelines**	**Midterm Exam II**
Week-14		**Student Presentations**
Week-15		**Final Exam**

Week 1: The Land Before Time

Learning about prehistoric technology involves knowing its discoverers and inventors. Thus, our first item on our itinerary is to meet them¸ our first "mechanical engineers," *Homo habilis* or the "Handy Men", who discovered and made the first stone tools, ca. 2.6 Ma. We continue introducing what we will refer to as our *paleofolk*, *mesofolk*, and *neofolk* (ancient engineers extant during the Paleolithic, Mesolithic, and Neolithic Ages) and their technological achievements. We owe these folks a great deal for their discoveries and inventions. It would be hard to imagine what we would do now without their ingenuity in discovering fire, introducing cooking technology, and inventing and standardizing stone tools during these stone ages. Understandably, such technological advancement corresponds to an improved encephalization process (evolutionary brain growth). In the beginning, our paleofolk used only their senses to discover things, mainly sight and touch. But when their brains grew bigger, their reasoning process developed, allowing our neofolk to invent more complex products. In this first leg of our trip, we expect our students to be exposed to our primordial engineers, their brains and the development of their reasoning process; students are expected to understand the differences in discovery, semi-invention, and invention in both historical and engineering contexts.

Week 2: The Rock

The next item in our itinerary is to visit and study the materials our ancient folks used to design and engineer their tools. Despite the uniqueness of each form of stone-tool technology, we can see the influence of traditions that spread spatially and temporally. Most of these stone tools had one thing in common: they were knapped and flaked from a particular type of rock called flint, which has a Mohs scale hardness of 7 (1 is for talc and 10 for diamond) and is ideal for use for prehistoric tools (**Fig. 1**). In addition, the conchoidal fracture mechanic of flint is predictable, and made flint easily knappable. Later, the technology of these tools evolved, following the evolution of their makers: from very primitive, crude and large human-made lithic tools, mostly core-tools, ca. 2.6 Ma, toolmakers graduated to smaller flakes known as hyper-microliths, dating back tens of thousands of years and measuring mere millimeters, with craftsmanship comparable only to modern diamond cutters. Specialists today have collected a truly amazing selection of stone tools from around the world. Although such technological prowess is stunning, it took our ancients a staggering amount of time— millions of years, in fact —to reach this point. In this part of the course, our students learn the sequences and mechanisms behind these tools, from the most rudimentary to the most sophisticated, that even modern engineers would have a hard time simulating without the use of modern devices.

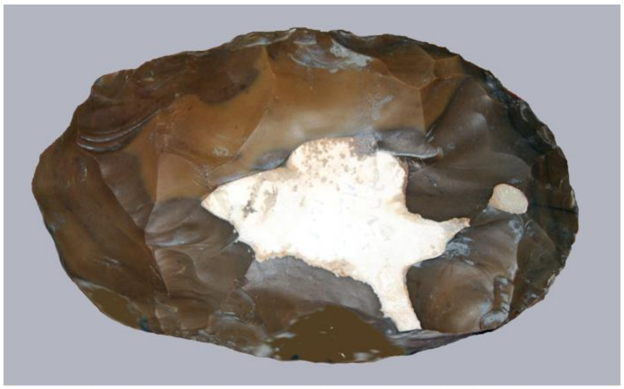

Fig. 1. A stone tool made of flint (Amman National Museum, Jordan)

Week 3: The Handlers

Initially, all tools were held directly in the hand, giving their users direct control over them. However, when our paleofolk began to change from nomadic hunter-gatherers to settlers, they had to clear trees and bushes from land for agricultural and pastoral farming. They found it difficult to fell large trees with their stone axes, and soon realized that they had to retool their implements by furnishing them with hafts (**Fig. 2**). In doing so, they allowed the use of two hands to harness greater speed (translated into greater kinetic energy or power) as well as an increased working radius to cut larger trees, while reducing risk of injury from impact and vibration.

Once familiar with such tools, they would never return to the old hand-held implements. The tools used for hunting, farming, cooking, fighting, and many other survival and living activities would never be the same. In fact, the mouse we use with our computer is a descendant of the haft which, instead of clutching an axe head, now holds the cursor on the screen. In this lesson, students will learn how our ancient engineers invented various handles for their tools to reach higher productivity, efficiency and ergonomics, and how a handle will deliver more kinetic energy during impacts between stone tools and objects. In this stage of our time travel, our students will associate the use of handles in ancient times (hafted tools) and today (e.g., golf sticks and baseball bats).

Fig. 2. A hafted tool from Papua New Guinea (Bali National Museum, Denpasar)

Week 4: Animal Farm

Once our neofolk equipped themselves with hafted tools, they were able to clear land and begin experimenting with their first agricultural engineering activity, i.e., domestication, another milestone in human discovery and invention. The domestication of animals and plants, which was likely discovered serendipitously, is commonly assumed to have occurred during the Neolithic Age. It was the human ability to reason that had promoted the cooperation with their fiercest competitors, wolves, in hunting for meat; hence, we see one of the earliest instances of domestication known in history, cementing the role of the dog as “man’s best friend.” Various other plants and animals followed suit. By the time we reach the Neolithic Age, we will have learned from many ancient cultures in numerous parts of the world, whose petroglyphs left us an invaluable legacy, analogous to present-day history books, about their customs, farming practices, dwellings, animal husbandry practices, and other quotidian activities. Here we will find prehistoric “open-book documents” about the livelihood and engineering practices of our paleofolk, mesofolk, and neofolk. As our primordial agriculture engineers gravitated towards farming and animal husbandry, their activities required water; even in places where water was plentiful, construction and coordination of irrigation and drainage were mandatory. These necessities motivated our early agriculture, mechanical, soil, and construction engineers to invent water-raising instruments and agricultural equipment, such as the Egyptian *shadufs* (water-raising lever) and *saqiya* (water-raising gears), Syrian *noria* (water mills), Persian *quanat* (water tunnels) and Chinese *karez* (water tunnels), all of which are so fascinating and efficient that they are still in use around the world even today. Once water was raised, our ancient surveying and construction engineers would be in charge in transporting it through channels and ditches. They had to measure the slopes (hydraulic gradients) of these trenches; and hence, they invented surveying instruments such as the Etruscan *gromae* and the Greek and Roman *chorobatae* and *dioptrae*. A dioptra is shown in **Fig. 3**. In this part of our voyage through time, our students will learn how and why these tools were used. Basic (high school) engineering physics and geometry will be used by students to establish the reasoning for the use of these instruments.

Fig. 3. A dioptra with a vertical and horizontal protractors

Week 5: Best is Water of All

The title of this section was stated by Pindar, a 5th century BC Greek Poet in The Olympic Odes (Ode I, Strophe I). This was also the main reason why almost all ancient settlements flocked to bodies of water. Besides its consumption, our paleofolk treated water with ultimate respect, especially when they wished to use it as a means of transport. Water transportation had been mastered since our paleofolk traveled from one island to another. They probably built very primitive rafts, hitchhiked on floating landmasses, or even swam short distances across a body of water. Later, our neofolk designed numerous rafts made from bamboo poles, clay pots, and inflated animal skins. These developments gave birth to the construction of various floating containers made from baskets covered with waterproof

Fig. 4. A Solar Boat of Khufu, Pharaoh of Egypt, ca. 26th century BC, Gizeh, Cairo Egypt.

membranes, such as *coracles* in Asia, *cufa* in Iraq, *curagh* in Ireland, and bull floats in the Americas. These floating containers promoted the emergence of the first boats, which were made from dugout logs (Europe), papyrus reeds (the Americas and Egypt), and *hobolo* (Africa). These boats were built based around the concept of buoyancy, i.e., the difference between upward force on the bottom surface of a body and the downward force working on the top surface; however, the ancients built these boats based on experience rather than hard physics. Archimedes, however, introduced the mathematical concept of buoyancy in the third century BC. In essence, he postulated that the weight of a floating log is equal to the weight of the displaced water; however, the density of the log is less than that of the water. This concept is still in use today by naval engineers for designing ships. At the end of this lesson, students will learn about the construction of the solar boat belonging to the Egyptian Pharaoh of Khufu (**Fig. 4**), who built the Great Pyramid of Giza. Khufu placed a disassembled solar boat in the pit next to his tomb with the intention to reassemble it in the afterlife and sail in it to meet his maker: the sun-god Ra.

Week 6: The Clay Masters

Traditionally, our European neofolk were credited with the discovery and invention of baked-clay technology; however, recent findings have revealed that our paleofolk in China and Japan had already made them long before their western counterparts did, thus shattering the notion that this technology is associated with the Neolithic Age. Our ancient 'clay masters' gained their knowledge through trial-and-error over thousands of years of experimenting with baked clay vessels. Their products were primarily used for utilitarian purposes, i.e., as pots or containers for grains, water, wine, and oil. Some used them for all purposes from womb to tomb, from storing placentas from childbirth to containing the ashes of their dead. Most of us do not realize that pottery-making, from its humble dirt-borne beginnings to its later status as an often exquisite work of art, entailed numerous processes that involved extensive chemical and physical engineering concepts; these processes were experimented upon by ancient elemental engineers through trial and error. The quality of

Fig. 5 Jin Dynasty, ca. 1115 – 1234, Zhenping county (Henan Provincial Museum Zhengzhou, Henan Province, China)

soil that allowed our ancient potters to exploit their artistic and engineering fortes to create several kinds and styles of ceramic vessels was an added bonus. One example that has stood out in terms of quality and purity would eventually become known as porcelain or china. Père F. X. d'Entrecolles, a French priest who visited a place called Gaolin, in Jingdezhen (the city of Jingde) of the Jiangxi Province, China, in the late 17th century AD, found that a certain white clay, which has since become known as kaolin or china-clay, was the material that ended up becoming celadon and porcelain[1]. A Jin Dynasty kaolin pottery is shown in **Fig. 5**. The Chinese had already used this clay mineral for over four thousand years, while in the West, kaolin was introduced by d'Entrecolles as recently as 300 years ago. Kaolin originates from granite, and when subjected to weathering, washed away, or broken into pieces, it will produce mineral clay. If we visit the western parts of the world, early Italian potters caught up with the technology and artistry more quickly than their counterparts in many other countries. Thus in this part of the trip, we see the emergence of *bucchero*, or black pottery, introduced by the Etruscans, a mystifying tribe in Etruria, around the 7th century BC. At this time, trade with neighboring Greece flourished, especially in southern Italy. At the time, Greek potters just happened to be at the apex of their skill in pottery-making. Eventually, Greek influence overwhelmed Italian pottery design, and Greek art spread to Italy, promoting the Geometric and Orientalizing styles of art pottery. A couple of centuries later, around the 5th century BCE, the black- and red-figured styles of pottery became the most traded ceramic vessels in both Greece and Italy. These vessels have become a great source of information, as potters and painters exploited the pottery surface, decorating it with their own graphic novels. They often autographed the vessels, promoting themselves as ancient celebrities. Here, our students will learn how and why clay was transformed into baked clay vessels using rudimentary engineering physics and chemistry. They will also learn of the kinds of materials which produced the desired outcomes.

Week 7: Heavy Metal

When early metallurgists discovered metals, they entered an entirely new dimension of art and technology. Just as they learned when using rocks as tools, they discovered that not all metals were the same. Some were heavier, more precious, more durable, more workable, more beautiful, and harder than others. The first metal they employed was copper; the ancient metallurgists used it to cast knives, cleavers, daggers and other fighting tools, until they realized that copper was too soft. Then they accidentally discovered that mixing copper with other metals considerably enhanced its performance. For a while, they were satisfied with an alloy of copper (90%) and tin (10%), known as bronze. Ancient metallurgists were able to smelt and melt copper, tin and bronze in open fires, because their melting points were low and attainable using this simple firing method; however, when charcoal-making was invented and kiln designs improved, ancient metallurgists were able to produce fire that could reach higher temperatures and melt iron, a harder metal that would become the metal of choice for millennia to come. This considerably changed the design and engineering of tools.

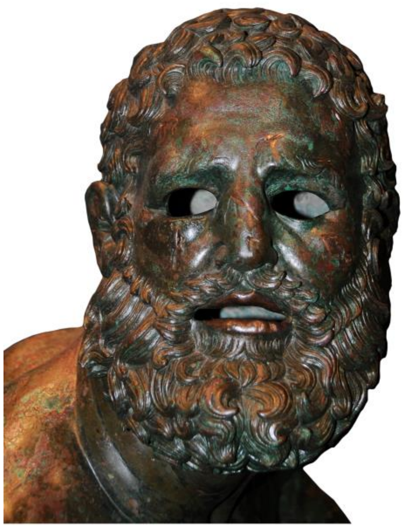

Fig. 6. Thermae Boxer life-size bronze statue, ca. 2nd - 1st century BC (Palazzo Massimo alle Terme, Rome, Italy)

Now our neofolk were able to advance various techniques of molding and casting iron that they had learned from earlier metals. These ancient metallurgists designed molds and casting tools using various types of metals. Sand casting, where sand was used as the mold, was probably the first method of producing metal tools. In these sessions, students will follow the step-by-step operations of ancient metallurgists creating their metal products. Casting more complex objects called for a different approach, first introduced in Egypt probably 6,000 years ago: the *cire perdue* or the lost-wax technique, in which a beeswax sculpture was employed to create a mold and lost when the mold was heated. The space left by the wax within the mold was then filled with molten metal. The mold was broken and discarded after the metal object cooled down. This age-old technique was perfected in the West by the Greeks and Romans (**Fig. 6**), and is still being used to this day. In this part of the course, students learn to simulate the various casting processes from sand casting to *cire perdue*; they are expected to gain the knowhow and reasons for each casting technique our ancients used.

Week 8: Historical Perspectives of Perspective

In the realm of engineering graphics, the quest for 3-D images was not new. In one of the caves of the Grotta di Fumane, near Verona, Italy (**Fig. 7**), we witness the first attempt of elemental graphic engineers to represent their three-dimensional world in two-dimensional parietal art. From the front view, the 30,000-year-old image of a shaman looks like a simple red ochre "stickman" painting on a flat surface; however, if the piece of rock is turned to show its side-view, one can see that it is not flat but rather has a ridge, upon which the shaman's body was painted. It is likely that the painter attempted to draw the 'torso' of the stickman protruding from a flat surface, demonstrating the intent to recreate the appearance of three-dimensional objects in two-dimensional images. Our paleofolk had begun experimenting with both mobile and parietal arts, and when they attempted to merge these two artworks onto a flat surface, they did so in what we now perceive as a distortion. For about 40,000 years, we have been experimenting with projecting three-dimensional objects onto canvases, using such strategies as overlapping (layering) the objects, furnishing them with shadows, shrouding them with mist and clouds, and placing them on top of each other. The perceived depth we were searching for, however, would be discovered only ca. 2,300 years ago, and is credited to the ancient Greeks[7]. It had to be a 'giant leap' for them to foreshorten distant objects, such as painting one's arm smaller than the other just because it was projected farther away from the same body. Then, after a hiatus, in the 15th century AD, foreshortening and linear perspective made a comeback after Brunelleschi repackaged them through mathematical computations. We are still using this concept in another attempt to merge the 2D and 3D environments in a virtual environment. In this part of the course,

Fig. 7. A shaman's body (left, front view) was painted on the rock ridge (right, side view), Fumane Cave, Italy, ca. 34 to 32 ka (Sant'Anna d'Alfaedo Museo Paleontologico e Preistorico, Italy)

students learn the various types of foreshortening in engineering graphics from both the historical and engineering perspectives. They would see temporal and spatial pictures about how far have we come from ‘perceived distortion’ to what we now call ‘virtual reality.’

Week 9: Simple Machines

As we continue our time-traveling journey, we are now millions of years away from the rudimentary stone tools our paleo-folks designed and engineered. We now developed the engineering reasoning to design simple machines, or devices that would furnish us with mechanical advantages. They include inclined planes, wedges, pulleys, wheels and axles, screws and levers (see **Fig. 8** for some of these machines). They were already in use by our early mechanical engineers to load, pull, push, carry, lift, move and do other operations that would facilitate the performance of their daily chores, such as pulling or pushing building materials to higher elevations (ramp), cutting trees (sharp wedges), lifting stones (pulleys), carrying loads in carts and wagons (wheels and axles), transporting water from lower to higher elevations (water screws), and moving or lifting objects (levers). In this session, students will be introduced to Archimedes’ ideas (ca. 287 BC) in designing his levers and screws, from both historical and engineering perspectives. Students will have a better understanding of how Heron, a Greek engineer (ca. AD 10 – 84) came up with the concept of a *aeolipile* or steam engine; although it was never applied, it provided the foundation for James Watt to invent the rotational steam engine (ca. AD 1787 – 1800) during the Industrial Revolution. In order to understand these techniques, our students will be given example problems that require the use of very basic engineering physics techniques.

Fig. 8. Simple machines: wheels, pulleys, levers (Deutsches Museum, Munich, Germany)

Week 10: Military Engines

A major application of simple machines in this travel itinerary was to create military engines. Although the use of these engines flourished in ancient Persia, Carthage, Gaul, and Greece, no other nation used them as intensively and extensively as the ancient Romans, whose economy depended largely on invading and looting other countries. In doing so, they proliferated the design and engineering of military engines; thus, this part of the itinerary will be dedicated to ancient Rome. The Romans designed and constructed *circumvallations* (besiegers' lines of fortification facing inward to block the besieged from escape) and *contravallations* (besiegers' second lines of fortification facing outward to counter the allies or rescuers of the besieged) to blockade their enemies[2,4]. As cruel as they were, the Romans had an incredible amount of patience, and their sieges would often last for years at a time; in fact, Roman sieges were often combat-free events in which they would literally starve their enemies to cannibalism or death. As a rule, after a siege was won, they would spare no prisoners; rather, they would slaughter the entire population of the besieged, regardless of age and gender, and loot their belongings. It was during these sieges that they designed and engineered numerous siege engines such as *vineae* (mantlets), *testudos* (movable military engines to protect troops while approaching the enemy complex), battering rams, and siege towers. They would also build numerous types and sizes of projectiles and artillery,

Fig. 9. A 1:6 scale model of an *onager* (Museo Della Civilta Romana, Rome)

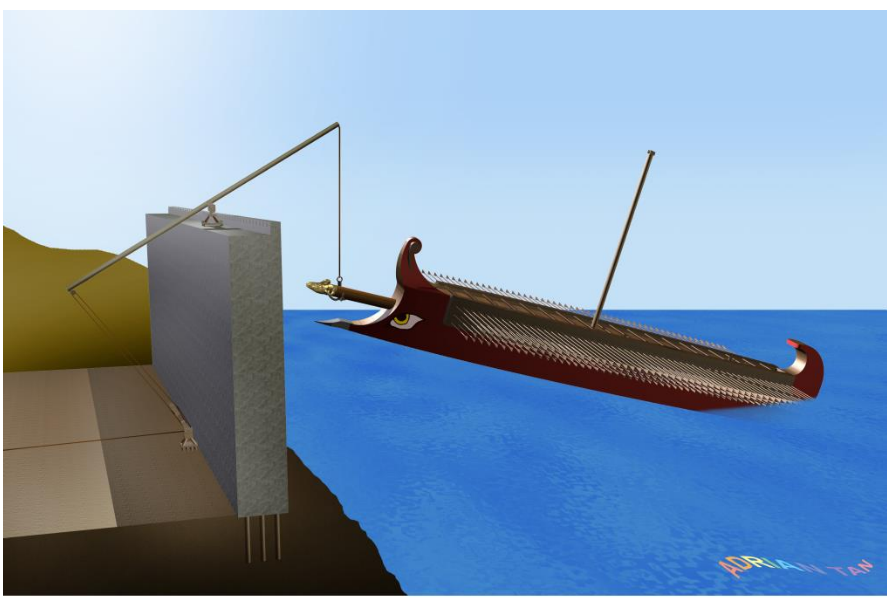

Fig. 10. Archimedes Claw in action according to Plutarch, ca. 3rd cent. AD

including *onager* (catapults) for hurling missiles towards their enemies (**Fig. 9**), and *ballista* for launching javelins.

Although Rome was initially not a marine nation, as it expanded its territory overseas, the Romans borrowed marine technology from other nations; and thus, they also became proficient in designing and constructing *monoremes*, *triremes*, and *quinqueremes* (warships with one, three, and five banks of oars, respectively). Since they felt more comfortable in hand-to-hand combat, they designed *corvi* to hook their ships to those of their enemies, so they could jump aboard their enemy ships. They also invented the *sambucae*, bridges installed on their ships that could be lowered down onto enemy forts as a means to swarm the enemy through the top of the battlement. But during the siege of Syracuse, home of the famed Archimedes, the Romans met their equal. Using the engineering concept of pulleys, levers, and buoyancy, Archimedes designed what was known as the *Archimedes Claw* (**Fig. 10**), a machine that would hook, lift and drop Roman ships that came close to his battlement [4,5]. Our students will learn how all of these siege engines, projectiles and marine combat technologies worked, to give them ideas of how to simulate them.

Week 11: This Old House

Our penultimate itinerary item in this time-traveling journey will be to examine how our ancient folks built their shelters from the ground up. It took about a million years for them to emerge from caves and feel comfortable enough to live in the open in built structures. We shall discover how they built the foundations of structures with wooden piles. Specialists call these dwellings *palafitte* (in Italian), or *Pfahlbauten* (in German), meaning ‘stilt houses’. This housing style still exists in many parts of the world today,

Fig. 11. A reconstructed Iron-age hut (ca. 3 ka), in Fidenae, near Rome, Italy

such as Palembang in Sumatra Island, Tonle Sap Lake in Cambodia, and Venice in Italy, in which stilt houses were constructed both on dry land and over bodies of water. These houses kept wild animals at bay and reduced the risk of being inundated by floods. As we approach modern times, we will see dwellings become more sophisticated (**Fig. 11**). Walls, columns and girders were strengthened through more elaborate bracings, so that houses could withstand natural forces such as wind and rain. We can watch designs, shapes, roofs, and building materials for dwellings improve. Logs became the first choice for walls, but when builders decided to construct basements, they would likely select stones for the walls instead. As they become more proficient in building their houses, we will see them begin to improve their excavation procedures, especially for their basements. We will tour the inside of some of their Iron-Age dwellings. As the number of inhabitants in a certain location grew, a village was formed; at first, these villages did not follow a specific pattern, but eventually, increasing population created a need to plan a small town. The earliest towns were probably located in Jericho in the Levant region; but the oldest continuously inhabited towns were likely in Luoyang, China. Among the earliest town in the West was planned by the Terramaricoli people from the now extinct Terramare culture. At the conclusion of this leg of our journey, we will take a sojourn in Ostia Antica, one of the oldest towns near Rome, which adopted terramare town planning and adapted it to the needs of a new tribe, blended from several others, that would later be called the Romans.

Week 12: It's About Time, Part I (Calendrical Timeline)

A voyage through time would be incomplete without knowing the origin of time itself. We will begin with prehistoric calendars, including Egyptian, Chinese, Mayan, and Roman calendars. We will continue with Roman calendars since their timetable would become the direct ancestor of ours today. The first was the Romulean Calendar created by the mythical Roman King Romulus (753 – 715 BC), who founded Rome. This calendar was far from perfect as it had only 10 months in a year. His successor, Numa Pompilius, ca. 716 – 673 BC, modified the timeline system by adding two more months (**Fig. 12**); however, about 1,700 years later, the Roman emperor Julius Caesar (100 - 44 BC) discovered that the calendar had meandered far out of control from the seasons, and was severely incongruent with the lunar and solar orbits. Caesar invited the Alexandrian mathematician Sosigenes to design a robust and intelligent self-repeating calendar for use without human intervention which would still follow astronomical movements.

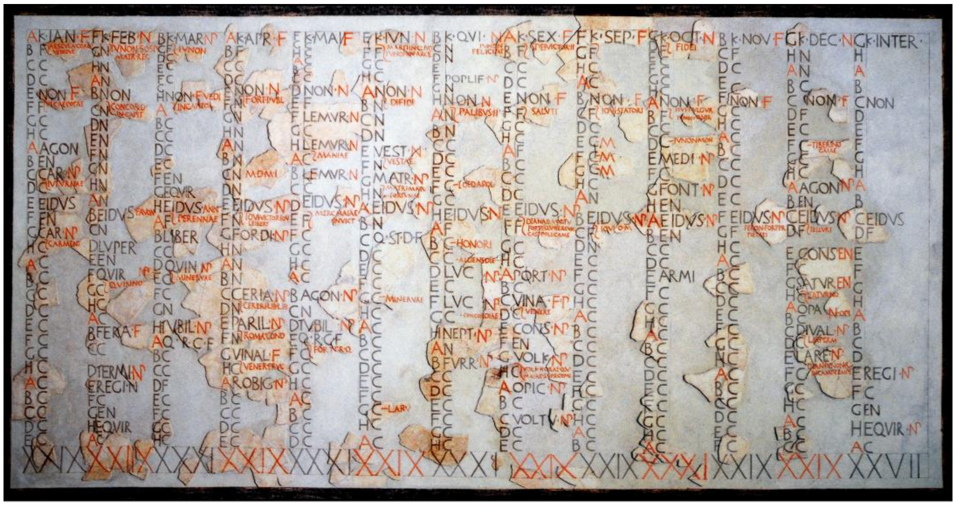

Fig. 12. A reconstructed Numan lunisolar calendar (Fasti Anziati or Antiates) from fragments of the fresco displays (Palazzo Massimo Alle Terme in Rome, Italy)

For the first time, his calendar would have an average of 365¼ days in a year. But to catch up with the slippage, Caesar added 90 days in the year 46 BC to make a total of 445 days. Suetonius[6], an ancient Roman historian, noted that in 46 BC, Caesar inserted 1 month between February 23 and 24, and two months between November and December, making it the longest 15-month year in the Roman history! Macrobius[3], another ancient Roman historian, called the year 46 BC *annus confusionis ultimus* or the 'final year of confusion.' Little did Caesar know, however, that in the next 1,600 years, his calendar had again slipped over ten days. Since Pope Gregorius did not wish to have another Easter that would drift away for days on end, in AD 1582, he referred to the day after October 4th as October 15 (instead of October 5th) and instituted the Gregorian calendar, the system we currently use. In this part of our time travel, our students will learn the reasons why a week has seven days, a month has somewhere between 28 and 31 days, a day has 24 hours, an hour has 60 minutes and a minute has 60 seconds. Students will also learn the preference of our ancient engineers for duodecimal (12) and sexagesimal (60) number systems instead of the decimal system.

Week 13: It's About Time, Part II (Horological and Atomic Timelines)

In this final part of our itinerary, we shall visit Pharaoh Thutmose III, who installed an obelisk in the city of Heliopolis and used its shadow to tell the time in around 1500 BC; it is considered the first sundial. Other nations from Phoenicia to China began using smaller sundials (*horologium solarium*) to measure time. But sundials depended on the tyranny of the sun. So the ancient Greeks began designing and constructing various types of *clepsydrae* or water clocks. In

270 BC, Ctesibius of Alexandria, an inventor and mathematician, created a water clock with constant flow which was considered to be the most accurate time- keeping device for nearly 2000 years. Hundreds of years later, Chinese clockmakers leapt to the forefront of this technology: Zhang Heng constructed one that was combined with an armillary sphere to observe planets in AD 132; I-Xing and Lyang Lingdzan improved another one in AD 724 by furnishing the clock with an *escapement* (a device used to regulate clock movement), and Su Sung eclipsed them all when in AD 1092 he built a ten-meter high water clock in which the escapement device moved his armillary sphere (**Fig. 13**). Other timekeeper apparatuses, such as sandglasses in the West and burning incense (fire clocks) in the East gradually appeared and did well for a while. For instance, during his voyage around the world, Magellan allocated 16 *ampolletas* (Spanish for hourglasses) for his ships for timekeeping and navigation. His pages maintained these *ampolletas* every hour or half hour in the ships. At last, in the late 13th century AD (1280 - 1300), the first mechanical clock was invented; it began its role as the sentinel of time, replacing other means of measuring time. These mechanical clocks were powered by elastic potential energy stored in a spring that was in turn connected to a gear train (gears interconnected through their teeth). But how did these engineers keep this energy from bursting out like a fully shaken bottle of wine that was suddenly opened up? Some of them might have remembered the escapement the Chinese invented 500 years earlier for their water clocks, and thus began the race to recreate this device to fit to their mechanical clocks. In the 17th century AD, Galileo Galilei introduced one that was based on the oscillation of a pendulum (**Fig. 14**), giving birth to the pendulum clocks or the "grandfather clocks" as we now call them, which could reach an accuracy of 100 milliseconds (one-tenth of a second) per day.

Fig. 13. A model of Su Sung's water clock, ca. AD 1092, (Henan Museum Zhengzhou, Henan Province, China)

As we fast-forward in our hypothetical time machine to the 20th century AD and beyond, we begin to witness modern engineers replacing the mechanical oscillations of pendulum clocks with the vibrations of crystal quartz. The new crystal quartz clocks would now be pendulum-free, and thus they became flagship timekeepers with an increased accuracy of about two milliseconds per day. In 1967, scientists discovered a new chemical element named *cesium* (or *caesium*), which was extracted from *pollucite*, a rare earth mineral that has over nine billion atomic oscillations per second; this prompted the invention of a new type of timekeeper, the atomic clock. But what do we need these clocks for? Modern engineers place these clocks in GPS (Global Positioning Systems) in satellites which transmit radio signals to receivers practically anywhere on Earth. The GPS system can provide geographical coordinates of any location on Earth using trilateration or lateral (non-angle-based) measurement based on the distance traveled by these signals (the product of time and the speed of light: 300,000 km/second). Our students can easily see that a time difference of 1 millisecond will lead to an inaccuracy of 300 km. In the age of unmanned aerial vehicles (UAV or drones) the role of atomic clocks is even more crucial; yet establishing accurate locations is just one use of these atomic clocks. For example, almost all telecommunications, computer network systems, and electric power grids currently require synchronization to about one-millionth of a second per day, which could be provided by the atomic clocks. Thus has begun an entirely new race of designing and engineering clocks with even higher degrees of accuracy, such as *optical clocks* which use atoms of aluminum, mercury, strontium, and ytterbium, and *quantum clocks* based on ions of aluminum and beryllium.

Fig. 14. A graphical reconstruction of Galileo's pendulum clock, ca. 17th century AD

III. Course Implementation

We developed this course, *History of Ancient Engineering* (ENGR 2361), with the goal of increasing students' technical literacy by increasing their knowledge of how technology has shaped human history and how people have shaped technology as well as the benefits and risks of technologies. At the end of the semester, students will acquire a new perspective on history and new knowledge of the genesis, evolution, and revolution of engineering, as well as understand the fundamental nature of engineering from various geographical, cultural, and historical perspectives, achieve the historical awareness of functions, aesthetics, designs, and analyses of engineering works, develop critical thinking about engineering problems not only with the when, where, what, and who but also with the how, made-from-what, and occasionally, what-if questions, particularly when an alternative ancient technology is contemplated.

In general, we expect students to place current engineering problems and issues in their larger historical context. Topics in this course may include agriculture, archeology, architecture, arts, chemistry, construction, geography, geology, hydrology, metallurgy, and physics (topics of constructed facilities such as ancient temples and pyramids are offered in another more specialized course). For instance, discussions of when, where and who invented ancient water-raising devices are no longer sufficient; the instructor is expected to discuss the engineering physics associated with these machines to answer why and how these devices worked. The *History of Ancient Engineering* was developed as a General Education Curriculum (GEC) course sponsored by the Engineering Education Innovation Center (EEIC) at the College of Engineering of The Ohio State University for all engineering students. The course is currently offered to students from various disciplines, engineering and non-engineering alike. For an optimal learning outcome, the number of students enrolled is limited to 36. About 10% to 30% of these students are non-engineers (non-engineering students who take this course in the summer term can reach up to 30% of the class population). For example, in the spring semester of 2015, our engineering students comprised those majoring in computer science and engineering (17%), mechanical (17%), chemical engineering (17%), electrical engineering (11%), civil (5%), aero and astronautical engineering (5%), and other engineering majors such as industrial, agriculture, biomedical, and environmental engineering constitute (17%) of student population. The non-engineering students majored in art and sciences and architecture are about 11% of student population. In the past, the performance of non-engineering students is generally either on par with or better than our engineering students. We have yet to study the reason, but our guess is that our engineering students are so used to more rigorous engineering problem solving skills, which are not expected from a history course.

The only prerequisite for this course is English 1110 (a first-year writing course). Although a high-school physics and chemistry background will help, the instructor may wish to discuss basic engineering principles that have been around for the past 2000 years (e.g., Archimedes' concept of leverage and buoyancy) without getting bogged down by the mathematical details. At the end of the semester, students will furnish projects in textual format (conceptual reports), graphical format (3-D images), or physical format (manually made or 3-D printed models) simulating an ancient device of their choice.

IV. Discussion and Conclusions

A question raised by a reviewer of this paper was related to the replicability of this course in other colleges. We expect this course to be replicated elsewhere with minimal resources. Most of the resources for teaching the History of Ancient Engineering course at The Ohio State University are associated with the release-time cost the college pays to the home department of the instructor and the cost of a teaching assistant (or minimally, a student grader who is paid on an hourly basis). As for the final projects, students have the choice to create reports that may be conceptual, graphical, physical, or any combinations thereof. Students (in groups of four) who elect to create a physical model will come up with their own resources (e.g., hafted stone tools, clay-baked vessels, *ballistas*, and *shadufs*) usually at a minimal cost.

In response to another reviewer's question about the potential of offering a follow up course, the Department of Civil, Environmental and Geodetic Engineering, sponsored by the Ohio State University Honors and Scholar Center, is currently offering for the first time in 2015, the CE 5860H (*Sustainable Ancient Constructed Facilities*). This course is a combination between the topics of construction and history (Construction History) in which undergraduate and graduate students learn ancient constructed facilities and evaluate their sustainability aspects. The topics include the construction of ancient **worship buildings** (e.g., Stonehenge, Karnak, Parthenon, Pantheon, Bulla Regia, Chichen Itza, Bingling-si, Todai-ji, Angkor Thom, Borobudur, and Besakih), **funerary monuments** (e.g., Mastabas in Meidum, Pyramids of Saqqara, Dashur, and el-Giza, Tombs of Qin Shihuangdi, Ming Dynasty Tombs, and the Taj Mahal), **water engineering** (e.g., Cloaca Maxima, Roman aqueducts, Dujiangyan dikes and spillway, *karez* and *quanat* water tunnels, *noria* water wheels, Srah Srang water reservoir, and *subak* Balinese water management system), **roads and bridges** (e.g., Via Appia Antica, Pons Sublicius, Caesar's Rhine River Bridge, and China's Zhao Zhou and Duan bridges), and **leisure facilities** (e.g., Greek theaters of Dionysos, Delphi, and Epidaurus, Roman theaters of Pompeii, Decapolis, and

Carthage, Curio's Double Theater, Roman amphitheaters of the Colosseum, Verona, El Jem, and Roman hippodromes of *circus maximus* and Gerasa, Jordan).

Yet another important question raised by the reviewers was related to the background of the instructor. We believe that historians with an engineering passion or engineers with a passion in history can teach this course. For example, the first author of this paper was a journeyman (a term used for a construction apprentice who moves from one project to another) who became interested in the history and culture of the numerous countries he visited during his construction project assignments. No text-book is currently available (the authors of this paper are in the process of writing one); however, a student course packet (combined lecture notes and work book) was created specifically for this purpose. Materials printed in the course packet were obtained from the authors' own data collected over a span of 40 years. Students' evaluations on the instructor's teaching performance are consistently favorable and each semester expects a waiting list of 20 or more students; we are hopeful that this is an indication of students' desire to learn from the past to better the future.

Acknowledgement

The authors of this paper gratefully acknowledge the reviewers' comments that have greatly improved this paper. The teaching of this course is sponsored by the Engineering Education Innovation Center of the College of Engineering at The Ohio State University.

References

[1] Burling, Arthur H. and Burling Judith. 1953. Chinese Art, New York: Bonanza Books, p. 153.

[2] Caesar, Gaius Julius (100 – 44 BC). 1845. Caesar's Commentary on the Gallic War, Adapted to Bullion's Latin Grammar, by Peter Bullions, 3rd Edition. New York: Pratt, Woodfrod & Co.

[3] Macrobius, Saturnalia, tr. Percival Vaughan Davies, New York: Columbia University Press, 1969, Book I, Chapters 13–14

[4] Plutarch (AD 46-119). Plutarch's Lives. Bernadotte Perrin, Translator, The Loeb Classical Library, London: William Heinemann Ltd, Cambridge, Massachusetts: Harvard University press.

[5] Polybius. ca. 200 BC – 118 BC. *The Rise of the Roman Empire. Translated by Ian Scott-Kilvert*, London: Penguin Books, 1979. Book VIII, No. 5.

[6] Suetonius (AD 69 – 140). 1965. Julius Caesar, in The Lives of the Twelve Caesars: Emperors of Rome, translated by Philemon Holland. New York: The Heritage Press, (40):30.

[7] Tan, Adrian H., Fabian H. Tan, and Frank M. Croft. 2014. "Historical Perspectives of Perspective." Proceedings of the 16th International Conference on Geometry and Graphics, Innsbruck, Austria.