Kalmar Nyckel: Using a 17th century
Dutch Pinnace to Teach Physics and More
DTI 2016-2017 Ancient Inventions

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Challenges

H.B. duPont Middle School, while located in a very suburban setting, serves a very diverse population. There are approximately 900 students in grades 6-8, with students almost evenly split between urban and suburban backgrounds. The academic readiness also varies greatly with relation to reading and math skills. It is not unusual to have a range of students reading all the way from a pre-primer level to those comfortable with high school text. In some cases the disparity is due to limited English proficiency. The math skills are similarly distributed with some students needing calculators for 2-digit addition while others are comfortable solving algebraic equations. To better meet student needs, our school piloted having honors classes in Science and Social Studies last year. Groupings were based on reading level for Social Studies and Math level for Science. The outcome was less than ideal for Science. At the middle school level, language skills are more important so that is now the basis of grouping for the 2016-2017 school year. In addition, our school is aiming for full inclusion. Students include those that have severe physical and/or emotional needs that interfere with their ability to interact linguistically, through either speech or writing. Despite these limitations, there is still an interest and an expectation to succeed in the Science classroom. The challenge is to incorporate the rigor of the Next Generation Science Standards, with its emphasis on student driven learning, while finding multiple access points for the students based on readiness.

Over and above their reading and math skills, Science background experiences are also highly variable. In theory, students who have attended Delaware public schools should have similar knowledge as there has been a K-8 spiralling curriculum with extensive teacher training and packaged kit instruction. Unfortunately, in many elementary schools, in striving to meet literacy and math goals, time has been taken from Science instruction. As a result, I need to do more on assessing prior knowledge and then scaffolding as I discover the gaps.

Introduction

I trod carefully upon the snow covered planking. There was a brief calm in the storm and the moon cast a pale gray light on the boards. It was my first time on night watch and I moved cautiously about the main deck, fearful of tripping and disturbing the others who still slept. I was even more afraid of what I might discover. I used the rope handle to pull me up to the foredeck, using my knee for balance. Had it been daylight, I would have been embarrassed for my fellow, shipmates to see me use this crutch, instead of jumping swiftly from the windlass. All seemed secure, lines neatly belayed and the fore course tightly reefed. I returned to the main deck, moving aft. I climbed the stairs to the quarterdeck, all seemed in order as well. Nothing left but to check the dock lines. I peered over the side, straining to see in the diminished light where the fore and aft springs attached. The ropes were secure and in position with padding so that they didn't rub against either the ship or the dock. Only the gangplank remained. With a sinking heart, I realized that I wouldn't be going straight back to my bunk but to the crew chief instead. The river and the winds had both conspired to shift the ship away from the dock. We were dangerously close to losing the gangplank with less than an inch of overlap between it and the side. The massive ship would need to be brought closer and it would need to be done before the change in tide. Even as I thought this, the wind began to kick up, further adding to the urgency.

"All hands to the windlass!" "All hands to the windlass!" "All hands to the windlass!" The ship's skeleton crew quickly assembles in response to the muster order, outer gear thrown quickly over various forms of night dress. "Man the poles." Man the poles, aye!" Wiping sleep from their eyes, the more seasoned members of the group grabbed the long wooden poles and positioned them in the various notched holes. Taller man on the outside, we worked in pairs. "Prepare to heave around." "Prepare to heave around, aye!" In unison, we respond, our muscles tensed. "Heave around". "Heave around, aye!" As first we pull, then push the poles past our chests, then our waists, until we stop near mid-thigh, our muscles straining to keep it in place. The windlass turns ever so slightly and the ship moves a fraction of an inch closer to the dock. "Ease to the pawl". "Ease to the pawl, aye!" With great control we let up slightly, allowing the windlass to turn back the smallest bit until it comes to a locked position. "Reposition poles." "Reposition poles, aye!". "Prepare to heave around". "Prepare to heave around, aye!" Again and again we go through each motion, fighting first the wind and then the tide, each time coming a little bit closer until our position was secure. Then at last comes the command we've been listening for "At ease", "At ease, aye!" we respond, stowing the long poles. Though eager to return to our bunks or at least below deck, away from the biting wind and bitter cold, we await our deck chief's orders.

"Congratulations! If you didn't consider yourself part of the Kalmar Nyckel crew before, you should now. Most of you are newbies, with only 2 days of class behind you, but you did an excellent job of working together." I looked around at the others in the group and met smiles similar to mine. We were certainly a diverse group. The veterans consisted of the two winter deck hands, both in their early twenties, one of who had acted as deck chief. In addition, there was an older couple, both retired, who had been scheduled for night watch before the storm. The remaining 7 of us were part of the current crew training class. When the request for volunteers to stay on the ship for the weekend to protect it from the storm came, we all answered, enthusiastic if green. Our ages ran from 14 to the mid-sixties and our occupations included graphic design, computing, banking, teaching, and chemistry. The youngest was a student at a performing arts high school and the oldest couple both recent retirees from Du Pont. Yet when the need arose, we all acted as 17th century Dutch crewman as we used the power of the windlass to move a 298-ton ship against the tide and wind with only a handful of people.

When the listing of DTI offerings included one on ancient inventions, I was immediately drawn to it as a 6th grade science teacher. Under the old Delaware state standards, an essential part of our curriculum was forces and motion. As a subheading, we looked at simple machines and how they could yield a mechanical and/or directional advantage, allowing people to do more work with less force. In previous years, under very scripted conditions, I had students investigate simple levers and pulleys in fixed and moveable positions. Using qualitative data, they connected how the distance of the force and/or the distance of the load from the fulcrum both affected the amount of force needed to do the work. With pulleys, they investigated both mechanical and directional advantages. For their culminating projects, I had students demonstrate their knowledge by constructing Rube Goldberg machines. While the students had fun, I'm not sure how much actual learning occurred. Some of my more mathematically inclined students grabbed on to the formula of W (work) = F (force) x D (distance) but it was isolated knowledge. This past year, as a sixth grade team, we decided to do a cross-curricular unit on Ancient Civilizations with the focus being on Ancient Greece, since it was an Olympic Year. Archimedes became my focus as I tied our investigation of the lever to a famous quote attributed to him: "Give me a lever long enough and I can move the world." We built catapults, launching marshmallows for distance and accuracy. To connect him to a non-military activity, we even attempted to construct a very simplified version of his water screw. Again, the students had fun, especially with the catapults, but I'm not sure about the learning.

Rationale

The current 6th grade unit on "Forces that Cause Motion" meets neither the Next Generation Science Standards (NGSS) nor the needs of my students. Although the science content is accurate, it is almost completely teacher-driven. It also has a large text-based component as students are expected to read the scientific theory before following a series of steps to demonstrate a principle. Lastly, having been designed by members of the Delaware Science Coalition, it references the science activities that students were presumed to have done in 4th and 5th grades.

I propose instead to create a series of learning opportunities using the Kalmar Nyckel, a modern recreation of the 17th century Dutch pinnace that was instrumental in bringing the Swedes to Delaware and creating the city of Wilmington. The ship is a living laboratory and students will be able to experience how three ancient inventions - the capstan, the windlass and the whip staff - are used to run the ship. They can experience first-hand mechanical and directional advantages based on the arrangement of the levers and pulleys that control the rigging and steering of the vessel. I want them to discover how the arrangement of sails - square rigged versus fore and aft - developed from the need to build bigger ships for transatlantic crossings.

The value goes beyond the Science classroom. As a team, we are required to design a unit of study that crosses all disciplines. Social Studies, English/Language Arts, and Mathematics are brought in as students take part in deciding how to outfit the ship to maximize profits and then compare their choices to the ones actually made. Mapping skills are employed in tracing the ship's multiple voyages. Thinking critically will come into play as students take a closer look at Peter Minuit. I hope to have the students argue about the content of his character.

Students will have the opportunity to read text at different lexile levels and to share their acquired knowledge through pictures, speech and written forms. Technology will be playing an important role in providing access to information and a platform to share it. Our school has supplied every 6th grader with a Chromebook. One of my goals is to have students collaborate using Google Docs and Google Slides.

Objectives:
Science

MS-PS2-2 Motion and Stability: Forces and Interactions

Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Although it may seem that one standard is not enough to base a unit on, the goal of the NGSS is not breadth but depth. In my role as scholar, I am learning about the engineering that is behind the sailing ships of yesterday, like the Kalmar Nyckel, and how some of those components have evolved into what is used today; for instance, the whip staff compared to the modern-day ship's wheel. The purpose is not to make my 6th graders experts on the ship but to help them develop an understanding of how pulleys and levers can be used to gain a mechanical and directional advantage. In addition, I want them to consider how wind power can be harnessed. As part of developing the NGSS, there is a greater emphasis on the science and engineering practices.

As the culminating activity, I would like my students to either design and create a wind-powered ship or design a way to lift the most force with the least amount of energy. Along the way, students will also be incorporating key common core standards for Math and English/Language Arts.

Big Ideas to keep in mind when developing this unit.

Enduring Understanding:

- An object's motion depends on the sum of the forces acting on it.
- Simple machines can provide mechanical and/or directional advantage to make work (change in motion) easier (use less force).
- Buoyancy is connected to relative densities. Density is the ratio of mass to volume.

Essential Questions:

- How can levers and pulleys be arranged to provide mechanical advantage?
- What is the relationship between distance, force and mechanical advantage?
- How do sailing ships use wind power?
- How is density related to buoyancy?

At first, I was not sure about being able to connect my own Kalmar Nyckel experience with Ancient Inventions. To start, I didn't view it as "ancient". The present-day Kalmar Nyckel is a recreation of a Dutch pinnace from 1625. Although my students may consider me ancient at 56, I worried that less than 400 years old didn't qualify as ancient. Secondly, and more importantly, I was worried about making my research and concurrently, classroom lessons, meaningful to both my students and me.

Initially my focus was too small: the capstan, windlass, and whipstaff as three examples of how two simple machines, the lever and pulley, can be used to direct the motion of a very heavy object (the ship) with minimal human effort. Then my focus shifted from Science to Social

Studies as my research centered on the maiden voyage of the original Kalmar Nyckel and the life story of the man, Peter Minuit, who was behind it.

Rather than providing clarification, seminar meetings were only increasing my frustration with my topic as I was being exposed to so many great ideas. Learning how the secrets of the Antikythera Mechanism were revealed using modern technology made me consider switching to the development of navigational aids such as the astrolabe and sextant. Having access to UD's rare-book collection with the examples of medieval medicine made me want to focus on what daily life on the ship would be like. Articles on engineering drew me to the shipbuilding process itself.

I continued my background research on the Kalmar Nyckel, both the original and the modern recreation. I felt my topic choice both too broad and too narrow. In deciding what I would share with my students, I vacillated between what was too easy: simple machines, too challenging: celestial navigation, and too removed from my science curriculum: Delaware history and the life and times of a 17th century sailor. It was actually the seminar on chronometers that brought things into focus.

Through my work with the Kalmar Nyckel Foundation, I had attended a lecture on the HMS Beagle (the voyage that included the naturalist Charles Darwin which would later lead to his theory of natural selection). Accurate chronometers were so essential to ocean navigation for longitude that the ship carried more than a dozen of the expensive instruments. When his backers denied him the funding for the position, the captain used his own money to pay for a clockmaker to accompany them on the voyage to maintain them.

"Necessity is the mother of invention" is an often repeated phrase but it has become the linchpin of my unit on the development and history of this fighting merchant ship. The Kalmar Nyckel exists as it does because of what was needed to trade efficiently across great distances. Rather than being a hodgepodge of disconnected ideas, my research on the vessel shows it in its historical and scientific context. My students will have the opportunity to work through similar issues in the classroom and also aboard the ship in this living laboratory.

Background

The Kalmar Nyckel Foundation

The Kalmar Nyckel Foundation (KNF) is a non-profit organization whose mission is to educate people of all ages, with a special focus on students, about the “Age of Sailing”. The Foundation’s current home is The Copeland Maritime Center at the Kalmar Nyckel Shipyard. The Copeland Center has three floors: the first is devoted to ship’s maintenance, while the third is for business offices, and the second floor focuses on education. Highlights of the second floor space include a partial scale model of the Kalmar Nyckel’s main deck, outfitted for the training of crew as well as the public. There is also a 19th century log cabin, moved from its original home in Ohio and a model of Fort Elfsborg, a Swedish fort in New Jersey. Although neither are native to Delaware, they are representative of how the original Fort Christina would have looked and how the homes the first Swedish and Finnish settlers would have built. There is also classroom space for STEM subjects such as buoyancy, navigation (a grid of decking on the floor can be used to teach longitude and latitude), sail-handling, sailing (which involves understanding wind vectors and balancing loads) and mechanical advantages.

In addition, the second floor houses KNF’s Watercraft of the World collection which helps people understand the importance of waterways in world history. Consisting of the 72 ship model collection of the Forney family, it showcases sailing ships from across time and around the globe. The foundation’s greatest asset however, is the living history ship itself, the Kalmar Nyckel. [13]

The Building of the modern Kalmar Nyckel

The Kalmar Nyckel is a recreation of the 17th century ship of the same name, a Dutch-build Pinnace that brought the first Swedish settlers to Delaware. It was built at the foundation’s shipyard on Wilmington’s historic 7th Street Peninsula. Over ten years of research and planning went before its creation from the late 1980s through the early 1990s. Designed by naval architects Melbourne Smith and Thomas C. Gillmer, the ship was constructed from 1995 to 1997 under the supervision of Master Shipwright Allen C. Rawl. It was officially launched into the Christina River on September 29, 1997, about 200 yards downstream from the site of the original ship’s first landing. [7]

The Building and Subsequent Service of the original Kalmar Nyckel

Built by the Dutch in 1625, the original Kalmar Nyckel was a “Pinnace” which meant that it was designed to operate as either a small warship or an armed merchant vessel. At the time in the 17th century, the Dutch were considered to be some of the best naval architects and shipbuilders in the world. She measured 93 feet on deck, stem to stern with a sparred length of 141 feet. Her original armament probably consisted of 12 six- pounder cast iron cannon, with two smaller swivel guns attached to the quarterdeck railings.

So how did a Dutch ship come to be in Swedish possession? At the time, King Gustavus II Adolphus (1611-1632) of Sweden was in desperate need of a navy. He had experienced great success with his armies and equally great disasters with his navy. He had lost ships to conquest and even had one scuttled by its own crew rather than be boarded and captured. What was to have been his flagship, the Vasa, sunk in 1628, while crossing the Stockholm harbor on its maiden voyage. The Vasa was a massive 1,400 ton 64-gun warship, a victim of unstable ship design. Lacking funds and time to build their own ships, the king put out a request to the town leaders of the major cities, asking them to purchase vessels as part of a Skeppskompaniet (or "Ships' Company".) A total of 16 ships, 100 to 150 feet long, armed with 12 to 16 cannon each were purchased. Stockholm provided four ships; Gothenburg two; and the smaller cities, pooling their money, providing the remaining ten. During wartime, the ships could be used for naval defense. In times of peace, the ships could be used for commerce, by the cities or by the Crown, with money coming back to the cities.

The Kalmar Nyckel was one of these ships, purchased from the Dutch in 1629 by the Swedish cities of Kalmar and Jönköping. The ship's name means the "Key of Kalmar," as it was part of the defense of the Kalmar Harbor. There is little evidence of how she was used between her date of purchase and 1634 when she was drafted full- time into the Swedish navy. Records of the period list her carrying 40 sailors, 28 soldiers, and 12 cannon – probably typical of her wartime strength. The ship largely disappears from the records again until 1637 when her greatest adventures commence. [7]

The Kalmar Nyckel and the New World

The Kalmar Nyckel's first journey to the new world can largely be attributed to the persistence of one man, Peter Minuit. In many history texts, he is the face associated with the purchase of Manhattan for the equivalent of $24 in trinkets and goods. It is an image made famous in a painting "The Purchase of Manhattan" by Alfred Fredericks circa 1910. [6] Yet it is a questionable history.

Although not part of the scope of my project, I discovered a very interesting site [5], which focuses on the many misrepresentations and historically incorrect depictions of the event. There is very little historical evidence about the actual purchase. "They have purchased the Island Manhattes from the savages for the value of 60 guilders; it is 11,000 morgens in size." wrote Pieter Schaghen, the representative of the State's General in the Assembly of the West India Company in a letter dated November of 1626. [16] The letter doesn't even mention Minuit by name, instead using the plural pronoun "they" to refer to the representatives of the Dutch Colony of New Netherland.

To understand Minuit's pivotal role in the founding of New Sweden, (Fort Christina), it is important to know a little of his background. Peter Minuit (born c. 1580-1589) was a Walloon whose Protestant parents had moved from Doornik, Henegouwen in the southern Netherlands, which then included present-day Belgium, to Wesel in Germany, in order to escape from religious persecution by the Catholics. On August 20, 1613, he married Gertrude Raedts, gaining himself both a bride and wealthy in-laws who probably helped Peter in establishing himself as a broker. In the mid-1620's, he joined the Dutch West India Company.

At the time, there was a great demand for animal pelts, beaver especially, and the New World was the source. In 1626, he was appointed by the company to become the new Governor-General of New Netherland, taking over from Willem Verhulst, the previous Governor-General. Minuit arrived in New Amsterdam on May 4, 1626. History suggests that the Manhattan purchase took place in either May or July, so it is quite possible that as the Governor-General Minuit would have brokered the deal. In any case, he developed a record of being a good trade negotiator with the Native Americans and brought great wealth to the Dutch West India Company over the next several years before being relieved of his position in 1632.

Back home, the political scene was very tense. It was a time of religious wars. Although Protestantism was widespread among the common people in Germany, the ruling class defended Catholicism. When Gustavus Adolphus, the Protestant king of Sweden, took city after city in Germany, Minuet cheered, and it was the king's death during a successful battle at Luzen that would become the pivotal moment of Minuit's life.

The king's only heir was his 6 year old daughter Christine, so the Swedish government was put in the hands of five high nobleman. Of this regency council, Count Axel Oxenstierna, who had served the king for 20 years, was the most influential. He believed that Sweden needed to develop her international markets, especially her copper resources. Unfortunately, Sweden's maritime experiences were very limited. Through a series of secret negotiations, Oxenstierna formed a partnership with several important Dutch businessmen. It was through his former superior at the Dutch West Indies Company, Samuel Blommaert, that Peter Minuit was chosen to lead this endeavor.

Minuit proposed that Sweden switch her focus from copper trading with Guinea to establishing an economic base in the New World. From here, she could not only trade her copper to the natives in the form of pots but also become a major distributor of fur and tobacco, as well as other goods to be had in trade. The first trip would carry soldiers and trade goods with the goal of purchasing the land from the natives and claiming it as New Sweden. In later correspondence, Minuet revealed that he had a second goal: providing opportunities for his friends and neighbors to escape war-ravaged Germany. His hope was that once a colony was established, Sweden would fund the passage of future settlers whose farms could provide more goods. It was a time of delicate negotiations. On the surface, Swedish and Dutch political relations remained the same. Concurrently, it became a matter of several private Dutch financiers influencing the ruling council of Sweden in order to achieve their common interest of financial gain, even if it didn't benefit Holland.

The establishing of a colony would require that its location be kept confidential. Minuit knew that the Dutch West Indies Company had made claims on all the Atlantic coast from New Amsterdam down to the Spanish holdings in Florida. Minuit knew the Dutch considered the Delaware River Valley as part of New Netherland but the boundaries were inexact. As of 1636, there was no Dutch settlement or trading post on the western bank of the Delaware River although there was Fort Nassau (present day Gloucester, NJ) on the east bank. Minuet argued that the west bank was adjacent to, but not part of, New Netherland. If the Native Americans would deed the land to Sweden, then a settlement there should not interfere in Dutch interests. He emphasized that a direct confrontation was to be avoided and his plan did not encroach on any land that had been formally deeded to the Dutch West Indies Company.

The Swedish Council was impressed with the details of the plan and agreed to form the New

Sweden Company. At the time, it was acceptable for government officials to invest in private ventures. The government could also supply money, goods or loans of ships to the company, which Sweden did. Instead of one ship and a sloop, the admiralty would supply a ship and a second smaller vessel, a yacht large enough for the transatlantic crossing. A smaller sloop would be constructed in Sweden but disassembled and carried as cargo to be reassembled and used for managing trade in the New World. The larger of the two ships was the Kalmar Nyckel and Fogel Grip, (Griffin Bird) was the second. It was named after a mythical four legged creature having the body and tail of a lion and the head and wings of an eagle. There is not much written about the Fogel Grip other than it was an armed vessel owned by the South Company, loaned to the Swedish navy and labeled a "jaght" which is a Dutch term that means a small craft or hunter. Minuet saw how the Fogel Grip could be used to hunt down Spanish prey should they come across any carrying treasure in their travels.

Outfitting of the Expedition

In 1637 the New Sweden Company (patterned after the Dutch West India Company) having procured the Kalmar Nyckel and the Fogel Grip from the Swedish Navy assembled in Gothenburg Harbor an expedition to establish a trading post in North America. Money, rather than national affiliation, seemed the uniting factor. The sailing crew was largely Dutch, while the Swedish government provided 23 soldiers under Captain Nilssen Kling and 30 muskets with 1 1/2 tons of gunpowder, and the expedition was led by the German Walloon Peter Minuit. It would take him almost 2 months to acquire the specific cargo that he knew would make the best trade goods and a successful venture. For ballast on the trip over, he insisted on bringing 500 bricks, purchased from a Gothenburg brick maker because he knew how hard life would be in the New World without bricks for fireplaces and chimneys. The fur trade had become so competitive that it wasn't just any cloth he brought but only that of certain color and quality of duffel (from the town of Duffel, outside Antwerp, where the cloth originated). Minuit's expedition finally got underway in late November 1637 only to encounter an unusually destructive North Sea storm. The two ships became separated and were almost lost. When the Kalmar Nyckel appeared in Texel, Holland, she had lost a mast, was leaking and needed a host of repairs. It would take two more days before the Fogel Grip arrived, also badly damaged. The two ships would not put out to sea again until the last day of December 1637.

Unwilling to further risk the winter storms of the North Atlantic, Minuit took the longer but safer route of first heading south to the Canary Islands then west across the Atlantic using the Northeast trade winds before travelling north up the North American coast. Early March saw the ships heading up what was then called Godyn's Bay before heading up the Delaware River.

Maps of this time show a variety of names for this area depending on the cartographer. Henry Hudson is credited with the discovery of Delaware Bay, in 1610, which he named the "South River", while scouting for the Dutch. In the year following Hudson's visit, Captain Samuel Argall entered the mouth of Delaware Bay. At the time he was exploring the Atlantic Coast on behalf of the English colony at Jamestown in Virginia. Argall named the great bay in honor of Jamestown's residing Governor, Lord De La Warre ("Delaware"). Yet it was the Dutch traders who came south from the New Netherlands colony in pursuit of fur trading that spurred on the first Delaware colonization. Their reports of seeing large schools of whales led Holland to send a small group of settlers to set up a whaling fishery along the southern shore of Lewes Creek at a place the Dutch called "Swanendael" (Swans Dale). This became the first recorded European colonial settlement within the territory of the state of Delaware. The leader of the effort to settle Swanendael was David DeVries. Among his backers was a wealthy merchant named Godyn. In his honor, Delaware Bay was called "Godins (Godyns) Bay" by the Dutch.

The story of Swanendael is a sad one. At first, the settlers and the local Native American tribe had a peaceful coexistence. In 1632, a misunderstanding over an alleged theft led to war ending with the massacre of every Dutch inhabitant of the settlement. DeVries, who was not present during the massacre, reestablished a settlement at the same location later in 1632 but abandoned it early in 1633. [3]

This overlapping of Dutch and English interests would later come to play a part in Minuit's fate. It was only because the Dutch settlement had failed that Minuit was now able to bring his ships up river. Minuit proceeded cautiously up the Delaware, heading the Kalmar Nyckel for the Minquas Kill (today's Christina River), a major tributary which flowed from the west. Minuit headed the ships about two miles up the Minquas Kill, where from prior knowledge he knew there existed a shelf of protruding rocks ("the Rocks"). These rocks would make an ideal natural landing site.

Using what he'd learned from his time as Governor of New Netherland, Minuit quickly established relationships with the prevailing Native American Tribes, the Lenape (sometimes called Delaware) and Minqua (Susquehannock) tribes. He negotiated a deal for exclusive Swedish rights to use and trade in all of the territory draining into the Minquas Kill and for permission to establish a Swedish colony to be sited on the western banks of the Delaware. Only after the papers of agreement had been signed did he claim the land in Queen Christina's honor and supervise the building of the fort that would bear her name, thus establishing the first permanent Swedish settlement in the New World.

Less than 3 months after he had landed, Minuit headed the Kalmar Nyckel back to Sweden in June 1638. His goal was twofold: report the success of his mission to the company directors and more importantly, based on that success, bring back a larger group of settlers including women and children to assure the colony's future. It would also be an opportunity to help his fellow walloons by getting them paid passage to a fresh start. [7]

In addition to the furs he'd acquired in trade, Minuet planned to stop in Virginia to bring tobacco back as well. Angered by the way that he had slipped between their two established settlements to establish one for Sweden, the Dutch and English jointly refused to supply him with tobacco. Rather than take the quicker northerly route, he again headed south with a plan to stop in the West Indies and exchange wine for tobacco. He never made it. Instead he met an old friend in the islands off St. Kitt's (St. Christopher's then). While both he and his captain were having dinner aboard the Flying Deer, a hurricane-strength wind hit the area. The Kalmar Nyckel came through with very minimal damage whereas the Flying Deer and several other ships were blown out of anchorage and all hands vanished. The first mate took control of the Kalmar Nyckel and spent two additional months in the area hoping for any signs of survivors before being summoned back to Sweden. It was an arduous journey peppered with another major storm that forced the ship to seek repairs in the Dutch West Frisian Islands and even more time in Holland because of a dispute over import duties before she finally made it back to Gothenburg, in early 1639, a round trip of 16 months. She would later make three more transatlantic round trips between 1640 and 1644 for a total of 4, more than any other ship in the Colonial Era.

The Kalmar Nyckel's story continued. She was re-outfitted and served honorably as part of the Swedish Navy from 1645 through her decommissioning in 1651 when she was sold to a Dutch merchant. Her fate after that is unconfirmed.

As a native Delawarean, I appreciate the ship's role in our state history. It was her four crossings that first established New Sweden, then helped it flourish by refreshing it with new settlers on its subsequent three journeys. As a scientist, I want to know more about her construction and how it enabled her to achieve what no other ship of the time period could. For those answers, I need to look to the present before looking backwards.

The Modern Kalmar Nyckel

To recreate the original Kalmar Nyckel, the designers largely followed the specifications of constructing a 1625 Dutch Pinnace. Aside of the equipment required by the United States Coast Guard and the United States Department of Transportation for the ship to be both seaworthy and carry passengers, it tries to be faithful in structure and ornamentation. The various carvings and decorative design touches are largely based on the Vasa, which was raised from the sea in 1961. My focus however is its structure and the way its parts interact that allowed its predecessor such success on the open ocean.

Dimensions

Sparred Length	141 feet
Length on Deck	93 feet
Length at Waterline	89 feet
Draft	12 feet 5 inches
Beam	25 feet
Height of Rig	105 feet waterline to main flagstaff 65 feet with topmasts down-rigged
Sail Area	7600 square feet
Displacement	298 tons
Registered Tonnage	168 I.T.C.
Rudder	3200 pounds

Navigational Aids: Astrolabes and Sextants

Today, we navigate using our GPS (Global Positioning System). Any place on Earth can be defined in terms of its longitude and latitude coordinates with amazing precision. Through the use of triangulation and orbiting satellites, computer programs are able to plot a course between any two points with little difficulty.

At the time that the Kalmar Nyckel sailed, navigation was much trickier. Mariners were able to calculate latitude (north and south movement from the equator) using an astrolabe. Popular in the late 15th and early 16th centuries, it was a brass ring, marked in degrees with an alidade (rotating pointer) that could be aligned with either the sun during the day or another celestial object at night (i.e. the north star). To find the latitude of the ship at sea, the noon altitude of the Sun was measured during the day or the altitude of a star of known declination was measured when it was on the meridian (due north or south) at night. The Sun's or star's declination for the date was looked up in an almanac. The latitude is then 90° - measured altitude + declination**.** [15]

The Mariner's Astrolabe was usually first cast in brass and then cut away which made it wind resistant but heavy. Although in theory simple to use, it necessitated looking directly at the sun and was affected by cloud cover at night. It also lacked precision, being off by as much as 4-5 degrees. Another navigation instrument in use at the same time period was the back staff, whose predecessor was the cross staff. Simple in construction, the cross staff was made of wood and consisted of a central staff with several movable sighting vanes. The back staff, developed around 1590 by John Davis, an Englishman, was a radical improvement. The back staff consisted of 3 vanes (sight, shadow, and horizon) and a pair of wooden arcs attached to a staff. It allowed measurement of the sun and moon in minutes rather than degrees and was used with the sun in the background, eliminating sun glare. Mirrors would come later to make it easier to use with celestial navigation. [17]

In theory, to go to a place of known latitude in the New World, the pilot would first go to the same latitude in familiar waters and then sail either due east or west until reaching the longitude of the new destination. Since sailing ships need wind, navigators had to alter their courses to make the most of both established and changing water and weather conditions. .

Engineering Specifications of a 17th century Dutch Pinnace

Trans-Atlantic travel, for the purpose of trade, called for a different type of ship. When sailing focused on moving up and down coastlines, maneuverability was paramount. There wasn't a need for either a large crew or the resources to sustain them over a long journey. On the whole, merchant ships were smaller and rigged fore and aft, allowing the sails to be managed with fewer people. All this changes with the pursuit of the New World's resources.

The current Kalmar Nyckel is a "recreation" of the original. There seems to be no record of any original ship drawings from 1620. Instead the designers relied on original naval documents from 1630 describing the ship's equipment and sail plan, contemporary paintings and artists depictions of similar ships of the time period and its ill-fated predecessor , the Swedish warship Vasa, sunk in 1628 and recovered, largely intact, in 1961.

The Dutch Pinnace was an armed merchant ship. Designed for ocean crossings, it is a four-masted ship consisting of a mizzen, main, fore, and bowsprit. It has three fighting tops (sometimes called crow's nests,) one each on the fore, the main, and the mizzen. When describing how a sailing ship is rigged, there are specific terms. The vertical spars are called masts with the exception of the Bowsprit which extends beyond the bow of the ship.

The bow is the front of the ship and the stern is the back of the ship. Facing the bow, the right is starboard and the left is port. Moving from the bow to stern is moving aft. In describing relative positions, if something is aft of something else then we say it is abaft of it. Athwart describes movement across the ship from port to starboard. Moving from the center line to either side is moving outboard. Conversely, moving from either side toward the center line is moving inboard.

The horizontal spars, on which the sails hang, are called yards. Each of the masts actually consist of two parts, with a Topmast and Topyard. The topmast can be lowered when needed to pass under bridges. In addition, although the area of the sail is smaller on the topyards than the main yards, the topsails are very important as they are able to use the more consistent wind currents that occur approximately 30 feet off the deck.

Ship's Description Bow to Stern

The Beakhead, or beak, is made of beams that form a catwalk-like structure that dips into the water in rough conditions. The sprit topsail was added to produce an upward lift to counterbalance this tendency. The lines for the forward sails were handled from the beak. Of more interest to the students will be that it is also where the naval term “the head” as a bathroom comes from as the two “seats of ease” - wooden boxes with holes for seats and no bottoms - are on the beakhead.

The Foc’s’le, or forwardcastle of the ship, is the area in the bow, under the raised foredeck. Hammocks weren’t used until after 1650 so sailors would sleep on coarse mats. A wood-burning fireplace with a tiled hearth served as the kitchen. A typical crew was 16-20 not counting officers with half sleeping and half being on duty.

The foc’s’le head, or foredeck, is the raised deck over the foc’s’le. There are no ladders so crew climb from the main deck to the windlass to the raised deck. The lines that control the forward sails are located here. It is a small space and a dangerous one to handle lines as there are no high railings on this deck as there are on others.

The main deck consists of everything from aft of the Foc’s’le to the coach. Many of the lines are handled on the main deck as are the hatches leading to the ship’s hold. There are two six pounder cannons and two three pounder cannons, named for the weight of their cannonballs. On the present day Kalmar Nyckel, the coach includes all the navigational equipment that is found on any other modern maritime transport, as required by law. Putting that aside, it is possible to sail the ship using only the 17th century technology of the whipstaff, described in more detail later.

The great cabin, also known as the captain’s cabin is located just aft of the coach. Dock lines for the stern are handled from inside the cabin. In addition to serving as the captain’s living quarters, it was also the ship’s office. “The Purchase Treaty of 1638” was signed here on the original Kalmar Nyckel between Peter Minuet and the Lenape tribal chief. [8]

The Quarterdeck is the raised deck at the stern of the ship. Its name relates to its size relative to the total length of the deck. Its sloped deck provides the best visibility and it is here that the conn (the person responsible for giving the orders to the helmsman) stands. On the recreation, there are curved staircases for access whereas on the original, there were probably rope ladders.

The area below deck on the modern Kalmar Nyckel is completely different than the original. In the 1620s, the hold was used to stow cargo, supplies for the crew, spare lines and sails and anything else needed to ensure safe passage. Priority would always go for trade goods either to be used for barter or to be sold on the return trip.

Using 17th century technology on the present day Kalmar Nyckel

There are three specific examples of 17th century technology that are regularly used on the present day Kalmar Nyckel: the Capstan, the Windlass, and Whipstaff.

The Use of the Capstan and Windlass in Refitting and Positioning the Ship

The capstan is a vertically-oriented human-powered winch. Up to sixteen crew members can haul tight a line wrapped around the drum of the capstan by marching around the capstan and pushing on the bars fitted through it with their chests. At the end of each bar, the capstan provides a mechanical advantage of 5:1. The capstan is especially useful for long pulls, as there is no need to stop to reset the bars. It also contains metal stops that keep it from slipping backward when there is no pressure on it. It can be used for handling dock lines, hoisting masts and yards, setting sail, and anything else the crew needs.

The windlass is a human-powered horizontally-oriented winch offering a mechanical advantage of approximately 10:1. The crewmembers wrap a line to be hauled around the windlass, and then up to eight hands use the long bars as leverage to turn it. A versatile device, the windlass is used for hauling back anchors, trimming sails, hoisting topmasts and yards, and any other use the crew might need it for. It has built in stops called pawls that keep it from slipping backward when there is no human pressure on it. Although it offers a greater mechanical advantage than the capstan, it has a shorter range of motion and requires that the poles be repositioned each time. In addition, because of the amount of force applied, there is a danger of cracking the windlass. The Kalmar Nyckel is currently on her second windlass in less than 20 years and it is showing signs that it will need to be replaced before too long.

The Use of the Whipstaff

In small sailboats, steering was accomplished with a stern rudder controlled by a hand at the tiller. In the 16th and 17th century, as sailing ships got bigger, the rudders grew proportionally, necessitating the length of the tiller to also increase. This combination became increasingly unwieldy and there became a need for a new way of steering: enter the whipstaff.

The whipstaff can be thought of as using a lever to control the rudder. On the end of a short tiller is a pin. Over the pin goes a ring, which is connected to the end of a long thin pole. The pole, known as the whipstaff, then passes through one or more decks. It was mounted loosely in a pivot so that it could slide up, down, and sideways. In this way the helmsman can steer the ship. [1]

The Kalmar Nyckel is outfitted with a whipstaff. Because of the placement of the helm aft on the main deck, there is very little visibility. As in the days of old, the helm receives commands from the conn, the officer standing on the quarterdeck. Because levers produce a mechanical advantage, the length of the whipstaff yields a 40:1 power boost so that it usually only takes one person to control a tiller large enough to control a 3200 pound rudder.
To move the ship to the right, the whipstaff is first taken out of the strap (a loop it rests in when the rudder is in a straight neutral position). Then the helmsman moves it slightly to the right to

change the direction of the ship before allowing it to come back to center so the ship can resume its forward motion. If a sharp change in direction is needed, the top of the whipstaff is moved all the way to the right until it almost touches the deck with the balance of the pole sliding below deck. This position is known as "in the hole" and can require two people to make it happen depending on the current and winds. To maintain this position, the helmsman will use her weight to keep the top of the whipstaff in place while holding onto a strap to keep herself in place. Movement to the left follows a similar pattern. Although there is a compass at the helm, navigation is usually done visually by the conn.

The Use of Sails in Tacking and Wearing.

Tacking is turning the bow of the ship into the wind, and bringing the bow through the wind. Wearing is turning the bow of the ship away from the wind, which brings the stern through the wind. Both serve to turn the ship around just using the whipstaff and the manipulation of sail power. In tacking, the goal is to bring the wind to the opposite side of the ship. Speed is important as one side of each sail is eased and the other hauled with the mizzen being used as a wind rudder. Wearing is done when there is a lot of room for a more gradual turn, the ship is sailing at a slow speed or there are rough seas.

How fast a sailing ship moves depends upon the direction and the size of the force of the air pushing against the sails. Running rigging describes the lines that control the sails and the yards. Moving the yards changes the angle of the sail to the wind. Setting a sail means stretching it out to catch the wind. Dousing a sail means taking the wind out of a sail by using lines to change its shape. There are different lines that control the different parts of each sail and they need to be handled in a certain order so that lines don't get tangled and control is maintained at all times. To minimize the effort needed to control the sails and yardarms, there is an extensive system of compound pulleys throughout the ship.

Student Exploration

Overall, this is designed to be a two week unit that ideally culminates in a visit to the Kalmar Nyckel Shipyard and Copeland Maritime Center. A tour of the actual ship fully-rigged would be ideal but it is not necessary for students to go on a day sail as the ship's replica offers the hand's on experience of hauling and easing lines. This unit could be done as a multidisciplinary experience with the Delaware History, World Politics, and Trade components being covered by the Social Studies teacher.

As a pre-visit, there is an outreach program called "Establishing a Colony" where students break into teams and roleplay different members of the first expedition. With group consensus, they discuss the limitations of the ship and make choices as to the people, weapons, and cargo they will bring. They then compare their decisions to those of Minuet.

Math teachers could explore multiple solutions by asking students to design three different plans and then calculate the profits from each. They could investigate average speed by comparing distance travelled to number of days. They can use modern GPS data to compute distance between stops and figure out those average speeds as compared to total time.

Art teachers could be involved by having students compare various representations of Peter Minuet and his “purchase” of Manhattan to look for any historical inaccuracies. In Language Arts, students could read about Peter Minuet from three different sources and compare the depictions. However, since my role is a 6th grade Science teacher, that is where my focus will be. To make this unit more universal, I have designed the activities to only use readily available materials and web resources.

My core idea is the interaction of forces. My lessons are intended to introduce students to the concept of mechanical advantage through the simple machine: the lever.

Lesson 1: Lift the teacher

The problem is to design a way to lift the teacher off the ground exactly 10 centimeters without touching me using a first class lever. Asking that it be exactly 10 centimeters forces them to think more. Some of my students weigh more than me so just lifting me off the ground isn’t much of a challenge. To be successful, they will have to change the distance from the fulcrum of both the load (me) and the effort force (themselves). My lever is a standard 8-10 foot wood plank and my fulcrum a wood block. Cans make poor fulcrums as they tend to roll or squash. For safety reasons, the student and I both pre-position chairs and hold on to the backs.

Prior to lifting me, students collect qualitative data on their perception of how effort force needed changes as the effort force moves further away from the fulcrum but keeping the load constant. As the lab sheet shows, students set up simple class one levers using a ruler, a pencil, a cap eraser, tape, a binder clip, and a weight.

Keeping the load (resistance force) at the same spot, they move where they apply pressure to make the lever arm balanced and reflect on whether it seems to take more or less effort. Quantitative data can also be collected using spring scales but it is not necessary. I’ve done both in the past and found that experimental error with using the scales actually interferes with understanding. The formula is that W (work) = F (force) x D (distance). Since the weight is the same, mathematically, if I double the distance of the effort force from the fulcrum, I should only need half of the effort force in newtons. Their readings rarely work out that accurately and it pulls the discussion away from mechanical advantage.

Another more reliable source of quantitative data is to measure the distance the effort arm is moving. A partner holds a paper on a clipboard behind where the effort force is being applied. The student uses the pencil to apply the effort force and its downward motion creates a line on the paper. The further the effort force from the fulcrum, the longer the line. Students can then measure the line and make the correlation between increased distance, less effort force. They could also create a point graph with a best fit line to discover that it is a linear relationship.

As a corollary, students do the complementary experiment where they keep effort force distance constant but move the load (resistance) force further from the fulcrum. Students then reflect on their experiments to look for any patterns in the data. They are then asked to apply their knowledge by designing the best placement of themselves, the fulcrum and me taking into account my weight and their own in order to lift me up 10 cm off the ground. Although each gets to try his/her plan, I don't grade based on a successful lift but on the relative placements in the plans based on their weights compared to mine.

Lesson 2: Discovery Video

The first lesson is followed by a Discovery video on simple machines which briefly covers class two and class three levers, in addition to screws, inclined planes, wheel and axles, wedges and pulleys. Students then go on a real/virtual building hunt to identify where simple machines occur in their lives. They look in the room, use resource books like "The Way Things Work" and "The New Way Things Work", and choose from previously selected websites. With each student having a Chromebook, I have found it a better use of time to put several research links into Schoology and have students choose from among them rather than spending their time wading through sites that are less appropriate and/or relevant. All students are assigned the site connecting simple machines to sailing ships. [2]

Lesson 3: Pulleys

Since pulleys are such an integral part of rigging, students investigate them as well. Working in groups of three, they see how the amount of effort force changes depending on whether it is a fixed or moveable pulley. They design compound pulley arrangements that provide both mechanical and directional advantage (fixed and moveable together pulling down) and those that only provide mechanical. They record their blueprints and describe the qualitative changes in effort.

This link [2] offers a great simulation for looking at compound pulleys. Students can watch the effort force decrease as the distance travelled increases. The formative assessment is a problem solving situation where they need to draw and describe the optimal pulley arrangement for a small boy to help a man get out of a deep hole using two pulleys, several lengths of rope and a tree.

Reflection

At this point, I want to pull the students back to the interaction of forces on a sailing ship. As part of a lesson on simple machines, they looked at how many bows are wedge shaped to cut through water. It is a natural lead into the shape of boats overall and why they don't sink. Many students have the misconception that all wood floats and that most metals sink. Investigating buoyancy would be a natural fit and students could do force diagrams, comparing loaded and unloaded cargo ships. In designing lessons that meet the NGSS, there is a push on using phenomena to activate learning. Every day there are cargo ships moving on the Delaware river with 2 different water lines depending if they are going to or coming from the port. Students will be exploring density in depth in their next year of science, so my focus is on having students investigate how changing surface area and thus volume affects buoyancy as measured by the number of pennies a boat can hold before it sinks. On a related note, I wanted students to consider the surface area of sails. Unfortunately, most of my research looking into sail simulations focused on sails that were rigged fore and aft where the Kalmar Nyckel, like most tall ships, are rigged square. My plan now is to build on their boat constructions by having them investigate the effect of adding sails using clay, straws and paper. Using a fan as the wind source, they will then time the crossing distance with different sail plans and look for patterns.

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Appendix

Next Generation Science Standards Addressed

MS-PS2-2

Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Delaware State Social Studies Standards Addressed

HISTORY STANDARD #4

Students will develop historical knowledge of major events and phenomena in world, United States, and Delaware history [Content].

Grade 6-8: Students will develop an understanding of pre-industrial United States history and its connections to Delaware history, including:

Three worlds meet (Beginnings to 1620)
Colonization and settlement (1585-1763)

GEOGRAPHY STANDARD #4

Students will develop an understanding of the character and use of regions and the connections between and among them [Regions].

Grade 6-8: Students will explain how conflict and cooperation among people contributes to the division of the Earth's surface into distinctive cultural regions and political territories.

ECONOMICS STANDARD #4

Students will examine the patterns and results of international trade [International trade].

Grade 6-8: Students will examine how nations with different economic systems specialize and become interdependent through trade and how government policies allow either free or restricted trade.

Common Core Math Standards Addressed

CCSS.MATH.CONTENT.6.EE.A.2.C

Evaluate expressions at specific values of their variables. Include expressions that arise from formulas used in real-world problems. Perform arithmetic operations, including those involving

Appendix (cont'd)

whole-number exponents, in the conventional order when there are no parentheses to specify a particular order (Order of Operations).

CCSS.MATH.CONTENT.6.RP.A.3

Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

CCSS.MATH.CONTENT.6.RP.A.3.B

Solve unit rate problems including those involving unit pricing and constant speed.
Use functions to model relationships between quantities.
Understand the connections between proportional relationships, lines, and linear equations.
Represent and analyze quantitative relationships between dependent and independent variables.

CCSS.MATH.CONTENT.7.EE.B.4

Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities.

Use properties of operations to generate equivalent expressions.

CCSS.MATH.CONTENT.6.EE.B.6

Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.

Common Core Literacy Standards Addressed

CCSS.ELA-LITERACY.RH.6-8.6

Identify aspects of a text that reveal an author's point of view or purpose (e.g., loaded language, inclusion or avoidance of particular facts).

CCSS.ELA-LITERACY.RH.6-8.8

Distinguish among fact, opinion, and reasoned judgment in a text.

CCSS.ELA-LITERACY.RST.6-8.1

Cite specific textual evidence to support analysis of science and technical texts.

Appendix (cont'd)

CCSS.ELA-LITERACY.RST.6-8.2

Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

CCSS.ELA-LITERACY.RST.6-8.3

Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS.ELA-LITERACY.RST.6-8.4

Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 6-8 texts and topics*.

CCSS.ELA-LITERACY.RST.6-8.7

Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

CCSS.ELA-LITERACY.RST.6-8.9

Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.