Fort Hays State University
FHSU Scholars Repository

Informatics Faculty Publications | Informatics

12-29-2022

Smart Classroom Designs v. 0.1

Gordon Carlson Ph.D.

Follow this and additional works at: https://scholars.fhsu.edu/informatics_facpubs

Part of the Communication Technology and New Media Commons, and the Educational Technology Commons

Smart Classroom Designs

Table of Contents

1. Overview of Project and Goals

The goal of this project was not necessarily to deliver a finished product, but rather to design and construct options for the smart classroom and report back on options so that libraries, museums, and other stakeholders can implement their own approaches. Rather than present a single, correct way to implement the smart classroom, this document highlights the iterative approach we took to developing options for physical, communicative, and technological aspects of the project.

The following sections in this document outline general approaches and alternatives that may be useful to stakeholders looking to implement a smart classroom. The iterations and considerations outlined in the following sections are presented in the context of project goals.

Cost Reduction. More advanced interactive learning spaces exist. This project does not aim to create a cutting-edge experience, but rather to provide useful elements of the best learning spaces in cost effective ways. This will increase the number and types of stakeholders that can create, implement, and benefit from a smart classroom experience. Therefore, options outlined in this document consider financial costs and technical capabilities to find a balance that errs on the side of affordability, even at the expense of more advanced smart classroom capabilities.

Portability. The smart classroom project aims to create a kit that can be deployed in one location, used by a stakeholder, disassembled, shipped to a new location, and then reassembled. Making a smart classroom that is portable is key to supporting the goal of bringing unique learning opportunities to rural, under-represented, or otherwise disadvantaged groups through sharing of resources. We set an internal goal of the entire project fitting within a standard eight-foot pickup truck to accommodate the most available and practical transportation options. In some cases, we found the better design for a component of the smart classroom could not fit within this constraint and may require alternative transportation options such as longer trucks, vans, or multiple trips to move and deliver the entire smart classroom. This issue is addressed in the following sections when describing alternative designs.

Accessible. This project does consider the design implications of providing a smart classroom for those users that require accommodations such as limited mobility, diminished vision or hearing, and fine motor skills. However, the primary focus of this document is on the construction and deployment of the experience; therefore, it is mostly concerned with the capabilities and needs of stakeholders that would initially build, (dis)assemble, or transport a smart classroom kit. It should not require advanced construction knowledge to build a kit. And it should not require advanced technical knowledge to deploy and make use of the smart classroom in the intended environments. We assume those building and deploying a smart classroom kit are university, library, or museum faculty or staff. We assume they have access to tools readily available in these locations or that are easy to procure from affiliated groups (maker spaces, facilities departments, or purchase at a hardware store). Further, we limit all materials used in the smart classroom construction to those available in retail stores or publicly facing resellers. For instance, the kit could be built using physical materials available at Home Depot, accessories available from Amazon.com, and electronics available directly from corporate websites selling products to the public (as opposed to specialty resources that exclusively sell to trade professions, educational institutions, or government agencies). These policies aid the ability to quickly design and deploy smart classrooms kits, but occasionally run counter to other goals. For instance, we avoid any design that requires tools for cutting metal. However, buying raw materials and cutting them to need would provide greater flexibility and long-term cost savings to the kit builder. We err on the side of not requiring the knowledge or tools to cut metal, limiting ourselves to prefabricated parts available at a hardware stores does, occasionally, raise the overall cost of materials. These tradeoffs are considered in the following sections, but those stakeholders looking to construct their own smart classroom kits are encouraged to consider their own institutional resources and abilities in determining the best strategy.

Interactive. The project was initially proposed with the end goal of making the entire smart classroom a touch-interactive experience. While options for this are listed in the following sections, a major outcome of this project was the evaluation of practical implementations for this approach. Ultimately, we determined that a robust and useful touch-interactive system that would correctly scale to the size of the proposed smart classroom is not compatible with other goals of this project. Successful approaches to this design are either expensive or technically daunting for the intended audience. Therefore, the appropriate sections below provide more detail on alternative input approaches because more time was spent experimenting with them than originally intended.

Technology Agnostic. Smart classroom kits are designed to be platforms rather than closed products. We avoid vendor lock in and platform dependence. The system could be run on Microsoft, Apple, or Linux platforms depending on the equipment and technical knowledge of the stakeholders. Our prototype and instructions are premised on the Windows 10 operating system and compatible software or hardware, but nothing about the overall approach limits users to just this version. Many of the specific use cases in our project employ off the shelf software (open source and commercial) in efforts to support the goals of cost reduction and accessibility. However, we also develop proof-of-concept software specific to potential use cases. Not all stakeholders will be capable of developing their own software for the smart classroom, but kits are designed on generic and standard equipment that a number of options for developing custom solutions are available.

2. Screen Frame Approaches

This section outlines four approaches to screens developed over the course of the project. While other ideas were developed, some either immediately proved to be inappropriate for the constraints of the project (see Section 1) or were considered to complex/expensive for the current version and are instead provided as potential future work for more sophisticated versions of the Smart Classroom (see Section 11).

Images and additional details are available on the project website. Costs are an estimate based on paying retail for parts from either nationally available vendors (such as Amazon, Walmart, Home Depot, etc.) or standard hardware, electronics, or home goods stores. Prices will vary, sometimes significantly, based on economic and regional factors. Estimates here are based on costs in the prototyping process and nationally available products at the time this report was written in 2022. Larger purchases directly from manufacturers or contractor supply companies may reduce costs. Costs are listed in US dollars.

Parts listed in the following sections are for one screen as different builders may choose to implement anywhere from one to eight screens using the approach in this project. Additional parts for supporting multiple screens are listed separately.

Materials for displaying the projected image are discussed below (see Section 3) and are therefore not included. Frames are designed to support a range of potential screen materials and switching from one to another has a minimal impact on overall cost compared to the overall expenses of the project.

a. Version A: Single Screen PVC

This was the first version of the screen built. It was generally cost effective but not as easy to transport or assemble/disassemble.

Part	Quantity	Cost
1.5″ PVC pipe (schedule 40)	60 feet	84
PVC 90 degree elbow	4	14
PVC 180 degree connectors	4	12
PVC slip tee connectors	4	16
PVC T junction	6	21
Alligator ring clips	40	15
2.5″ clamp clips	6	15
2.5″ inch long, 0.25″ threaded hex bolts	20	18
0.25″ hex nuts	20	6

This approach involved the fewest unique parts to purchase. It was cost effective in terms of materials but presented challenges. First, to create a screen nearly ten feet wide, long pieces of pipe were required. These pipes sag under their own weight and it was therefore difficult to provide a straight, horizontal top bar to support screen materials. Second, 1″ pipe was not strong enough and 2″ pipe was simply so large as it was not feasible for transportation. 1.5″

was selected as the best compromise. However, requiring pieces to range from 7-10 feet long presented challenges in storing and transporting the materials. The weight was manageable but not ideal. The volume of pipe occupied considerable space.

The length of pipes meant traditional pickup trucks and vans were not long enough. In the early trials, the team used a longer 16-person van to transport materials for testing. However, to avoid this, a modified designed was trialed that used longer pipes cut in half with connectors used at the time of assembly. This improved the transportation issue, but increased setup and tear-down time.

At the time of assembly, the most significant drawback to PVC pipe is the difficulty putting the pipe together and taking it apart. The nature of the product is the create tight seals. Schedule 40 pipe is used for water and typically under the assumption it will be glued together. "Furniture PVC" is available which is stronger, comes in a range of colors, and is easier to work with in terms of repeated connections. However, this is significantly more expensive. When assembling and disassembling screen frames, the team needed to use rubber mallets to deal with the tight fit of various components.

In addition, while PVC is relatively inexpensive, it is also soft. Cutting and assembling pieces is imprecise. The design for the PVC-only screen pushed the tolerances of the material. In user studies it was found that each time a group assembled a frame, it would be built to slightly different dimensions or tolerances because of the nature of the material. To combat this, we experimented with building PVC frames that were accurate and then drilling holes through the pipes and connectors so that bolts could be placed through them. This required more time to build the original frame, but given the reusability, this cost was negligible. The version of the PVC frame with bolts did provide improved structural integrity, but aligning the holes given the high-friction PVC fittings proved challenging in testing, especially with any users who lacked hand strength of dexterity. Leaving the frames mostly assembled during storage and transportation helped with this considerably, as it minimized the amount of bolts to be aligned and tightened each time the frame was assembled. However, hex bolts have a tendency to loosen during the bumpy transport of PVC stacked in a van or truck.

Ringed alligator clips were placed over the two horizontal tubes in the front of the structure and screen fabric was clipped to these to create the top and bottom of the display. These proved useful as they were inexpensive, reliable, and easy to use. The sharp teeth of the clips provided a strong hold on the fabric, but did begin to damage screen fabrics over time. The fabric was cut to be approximately six feet tall when stretched tight between the top and bottom. The fabric was cut to be approximately 16 feet wide so that it would be stretched tight over the vertical front pipes and then clipped to the rear vertical pipes. This created a generally taught fabric screen for the projector. The one major issue we determined with this approach was that the 2.5" clamp clips used to secure the screen to the back pipes required significant hand strength. The average person could likely perform this function, but people with limited hand strength would certainly find it difficult.

This version of the screen was the first we tested. However, its drawbacks, particularly its difficulty in creating multiple identical frames, led us to modify it by introducing metal components.

b. Version B: Single Screen PVC and Slotted Angle

This version of the screen frame is based on the previous one, but with the introduction of 1.5″ slotted angle irons. These are available in various lengths from hardware stores and we used a standard 6-foot long piece on either side of the frame. The metal is available in zinc-coating which is preferred, though does cost more.

This design incorporates a "floating frame" approach. A rectangular frame is built with horizontal pieces of PVC and vertical pieces of slotted angle irons. The frame is then placed on support "legs" and connected to a PVC frame to support the increased weight of the metal. Aside from the metal pieces, the remainder is quite similar to the first design outlined previously with only a few key changes.

Part	Quantity	Cost
1.5″ PVC pipe (schedule 40)	60 feet	62
6-foot slotted angle irons, 1.5″ wide	2	50
PVC slip tee connectors	12	48
PVC T junction	12	42
Alligator ring clips	40	15
2.5″ clamp clips	6	15
2.5″ inch long, 0.25″ threaded hex bolts	20	18
0.25″ hex nuts	20	6
3″ T slotted joints	4	10

Connecting the metal pieces to the PVC pipe was accomplished with the same hex bolts as the previous design. However, this led to angular sway since the bolts did not keep the metal at the necessary 90-degree angle. 3″ T slotted joints were used to provide three points of contact with bolts going through the PVC, metal t-shaped joint, and slotted angle iron. This provided the necessary angular stability, through it did require changing the configuration of holes drilled in the PVC pipe.

There are two distinct advantages to using the slotted angle iron for the vertical components of the frame. First, the metal is quite strong relative to both the PVC frame and screen materials. This means it does not bend or warp and can be relied on to remain straight. Second, the shape of the metal allows the screen fabric to be pulled tightly over the edge and turn a clean 90 degrees to the rear of the screen in order to create a much better straight edge for the projection screen. This improves both the ability to take the projector image to the edge of the frame and to align multiple screens with one another to create a more convincing continuous image with less gap between projector images. This second advantage is only realized if using short throw projectors that can fit their image between the metal bend and screen material.

The primary drawback to using the slotted angle iron is cost. It is significantly more expensive than PVC pipe. However, when we tested the initial construction, assembly, disassembly, and image quality, we determined it was well worth the additional investment and better accomplished the goals of the project (see Section 1) than the initial design.

The second drawback was that the metal is heavier and caused the frame to lean slightly forward. This didn't pose a structural issue, but it did results in the top of the projection screen being more forward than the bottom. Good projectors can overcome this through image management, but it is still not ideal. The easiest solution was to either place more weight on the back of the frame to hold it in, or to lash frames together so that each one could support the weight of the other when used in a multiple-screen setup (see Section 10).

c. Version C: Single Screen All Metal

This version embraced a higher cost for higher performance of the screen. In an attempt to make the screens smaller, easier to transport, and easier to assemble or disassemble, all PVC is removed and the entire screen is made from metal components.

Part	Quantity	Cost
6-foot slotted angle irons, 1.5" wide	2	50
4-foot slotted angle irons, 1.5" wide	6	154
3-foot slotted angle irons, 1.5" wide	2	43
1-foot slotted angle irons, 1.5" wide	2	16
6-foot punched steel flat bar, 1.5" wide	2	47
Large shelf bracket (18"x16")	2	30
Small shelf bracket (12"x8")	2	13
10-foot closet rod	1	16
2" pipe wall bracket	2	4
Alligator ring clips	40	15
1" inch long, 0.25" threaded hex bolts	20	18
0.25" hex nuts	20	6
3" T slotted joints	4	10
1-foot furniture leg	4	28
9" bed risers (four pack)	3	45

This version uses the same bolts as previous versions but no PVC pipes. Similar to the floating frame concept, this design creates a rectangular frame and then brackets them to legs. The rectangle is created with two vertical side beams from the 6-foot slotted angle irons. The horizontal bars and each comprised of three 4-foot pieces bolted together. The necessary size is not a standard one and would require metal cutting which violates project goals for simplicity and cost. By putting three shorter pieces together, the width of the screen can be variable and adjusted to the needs of a specific installation. This also avoids a single long piece of metal which would be difficult to transport in typical vehicles.

The frame is strengthened with the smaller brackets in the bottom corners. The pre-drilled holes align with the slotted metal requiring no additional drilling (unless the size of the holes need to be changes to accommodate a different sized bolt). T slotted joints are used on the top corners of the frame. Large shelf brackets are bolted to the bottom of the frame perpendicular, pointing backwards. The bracket is then bolted to the 3-foot pieces creating feet on either side. Parallel to the 3-foot feet on the bottom, the 1-foot pieces are bolted to the top corners of the frame and 6-foot punched steel flat bar is placed vertically, one foot behind the sides of the frame. In this way the frame is not sitting squarely on the ground composed entirely of metal.

On top of the open end of the 1-foot slotted angle the pipe wall brackets are attached providing a place to attach the closet rod the entire width of the frame. The top 20 alligator ring clips are placed around this closet rod and the fabric for the screen is stretched over the top horizontal slotted angle iron. This creates a clean edge for the screen at the top and removes the alligator clips from view of the user while the metal provides a straight edge that does not bend like the PVC.

This creates a frame six feet high. To place the frame at the correct height, it must be raised one foot. There are different options available. The two most successful options we tested are placing 1-foot furniture legs at each corner of the structure or setting the entire structure on a stack of three 9-inch bed risers. Both options work, but there are tradeoffs for cost and ease of use.

In our testing, we determined that this approach was superior to the first two for several reasons. First, all materials can be purchased retail, in a single hardware store, for a reasonable price within the constraints of the project (see Section 1). Second, the all-metal design provides significantly more structural integrity and can be built to exactly the same size each time by marking the holes used for each bolt. Third, the entire structure can be assembled, without any tools, faster and with less arm or hand strength than the previous designs. Fourth, when disassembled, the frames take up significantly less space than the PVC versions. Perhaps even more important, no single piece is longer than six feet. This is crucial for accomplishing the goal of transporting the entire system in a conventional vehicle like a pickup truck.

Drawbacks of this design include increased price, potential for cuts on the occasionally sharp corners of the metal pieces, oils on the metals causing stains on the screen fabric, and increased weight of the frame when carried as a single kit.

d. Version D: Single Screen Slotted Angle and Rolling Fabric

This version of the screen is nearly the same as the previous version. It is also made entirely of metal from the same parts. Only two changes are made. First the top perpendicular parts are replaced with 2-foot lengths instead of 1-foot. This provides the same one foot of metal behind the screen but adds an additional foot of metal coming off the top two corners, pointed toward the user of the screen. Off these pieces are hung a roll-up retractable screen from mounting joints. The metal frame is the same, but this version sees a solid screen material hung away from the frame instead of a fabric stretched across the frame itself. The rollup material is discussed in Section 3.

3. Display Approaches

The smart classroom is essentially a number of modular projection screens with the ability to see and track light from both sides. This section outlines approaches to constructing the display components supported by the structures outlined in the previous section.

a. Projectors

Because of the limited space within the smart classroom and the need to keep costly or fragile equipment away from users, the best option is to use rear projection for the screens. This places the projectors on the other side of the smart classroom walls and protects them from accidental contact. Read projectors can be mounted either on the floor or ceiling. Modularity and transportation concerns dictate the screen frames between light weight and not reliably strong enough to safely hold a projector seven feet off the ground. A standard rear projector would need to be lifted off the ground as high as the center of the screen. This introduces a need to include stands in each smart classroom kit and reduced image quality because the projector lens will have a "hot spot" where users will see the bright projector lens in the center of the screen. In addition, this style of projector would need to be anywhere from 3-5 feet away from the screen to produce an image as large as described in the previous section. This significantly increases the footprint of the kit and possible reduces the number of physical locations a smart classroom would fit.

Placing the projector on the ground closer to the screen not only negates these issues, but further simplifies setup and adjustment of the kit each time a smart classroom is setup in a new location. This requires short throw projector. While this is the ideal device, there are two potential drawbacks. First, this type of projector is more expensive. A sufficient front projector may be available for $500 but a sufficient short throw rear projector will likely be more than $1500. Second, this type of projector tends to be less bright than other types of projectors at the same price point. In our prototype we used a projector with a brightness of approximately 3,000 lumens. This is primarily designed to be used in spaces that will be dimly lit (such as turning off overhead lights when presenting material in a classroom). The brightness of a projector correlates to the distance between the projector and the screen.

Most standard projectors are designed to project a maximum image size of 8 feet. In our prototype, we designed screens closer to 10 feet. While the image was still clear, it exacerbated the brightness issue requiring the room to be dimly lit for most use cases. This works in many situations, but not in circumstances where users need to be able to see each other while using the smart classroom or when constraints of the physical space make it impossible to control lighting (such as having windows). To maintain visibility in lighted rooms and large display sizes, a projector with 4,500 lumens or higher is recommended. This will likely increase the cost of the projector.

Front projection is possible, but the projectors would either need to occupy space in the smart classroom (on the floor or a stand) and users approaching a wall would obstruct the image. The only solution to this is to mount the projectors several feet above the screens. However, this would suffer from the same drawbacks as ceiling mounted rear projection screens with the added danger of a falling projector landing on users.

The final consideration is resolution. To maximize compatibility with software and hardware, we rely on the standard resolution of 1920x1080 (also referred to as Full HD or 1080p). This is the most common resolution meaning there are many projectors that support the feature. Individual pixels are visible when approaching the projection screens close enough for touching, but we found this acceptable in nearly all use cases. Ideally, projectors showing 10-foot images should be a higher resolution of 3840x2160 (also referred to as 4K). This results in images with four times the resolution that look far sharper from up close. However, 4K projectors are certainly more expensive and the higher resolution requires a more powerful (and expensive) computer to run multiple screens at the same time. The benefits of 4K projectors will need to be balanced against budget and technology constraints by stakeholders building smart classroom kits.

For this prototyping project, we used NEC U321H short through projectors running over HDMI.

b. Screen Materials

In the process of developing the prototype we tested nearly 50 different materials for use as a rear projection screen material. When determining the best materials, we had multiple requirements to meet.

First, materials for front projectors are readily available and inexpensive. However, rear projectors require a screen material that passes light through rather than reflecting it. This property is less common among readily available materials. Second, in supporting our goals of cost reduction and accessibility, we sought materials that were easy to acquire and relatively low cost. After investigating several options, we found these goals to be contradictory. Third, a material that is easy to pack is key to making the smart classroom kit transportable. These issues are addressed for the various screen types below.

i. Plain Fabric

Fabrics readily available at retail establishments like crafting or quilting stores were affordably priced, but not available in the size required for a 10-foot screen. Typical bolts of fabric are up to five feet wide. However, fabric for the smart classroom screens needs to be at least six feet wide (even wider is ideal depending on frame design). Acquiring the materials in wider sizes often required ordering custom bolts from the factory which substantially raised the price. Alternatively, fabrics with useful properties and available at larger sizes were sold by factory direct or online-only businesses requiring larger purchases or prohibiting testing multiple fabrics without buying each one.

For fabrics, wrinkling and creasing turned out to be an important factor. Some provided good visual properties but either transported poorly, were easily damaged, or were difficult to keep clean. The two best materials in this category were a shear acrobatic fabric that was lightly woven with a stretchable quality which improved the ability to tighten the screen. It is lightweight and easy to store in a very small space. It comes in larger bolts from the manufacturer. The material is more expensive than traditional cotton, but it comes in standard sizes that are large enough for the project. The major drawback to the material is that it tears easily and is affected by the alligator clips used in the frame designs. In addition, while its shear nature created a good image on the screen, it also let a lot of light bleed through causing issues in multiple screen setups.

The other fabric was a traditional cotton with a higher thread count and a stretchy polyester blend. The material is sturdier and more resistant to tearing. The bright white color does show dirt more easily but can be laundered safely. The material handles light bleed better and still provides a decent projector image. The primary drawback is that acquiring the material in a large enough size likely requires a more expensive special order.

ii. Purpose-Made Fabric Screens

Several vendors produce pre-made projector screens. These are primarily a cotton-polyester blend fabric like the materials outlined above. However, these fabric screens come finished to various sizes. They have black solid edging making them stronger and often have grommets or Velcro loops for attaching to tripods for easy, portable screens. While more expensive than the raw fabric, we determined in testing they were well worth the expense as they are available in the necessary sizes from multiple online retailers (ours were purchased from Amazon).

Prices range from $18-$60 depending on size, quality, and availability. Velcro straps are particularly useful for affixing the screen to the frame without the need for as many small alligator clips. The finished product is stronger, and the finishing makes it easier to store without damage. Aside from cost, the main drawback is that some versions are not as easy to wash in a machine due to the metal or wiring contained in them.

iii. Window Treatment Materials

While it was not within the budget constraints of the project to build all six screens to this design, one was constructed to test. The screens for the Smart Classroom are essentially windows without glass. They are a frame through which a projector shines light into a material held up by the frame. A number of window treatments are available that are designed to hang off a frame to control the amount of light coming through. Our prototype uses a 9.5-foot rollup window treatment that is 60% opaque. It is six feet tall. It is mounted to the top of the screen frame overhang (see Section 2.d). In this way the screen can be pulled down when in use and pulled back up when not in use. The material performed well in testing, though the image was somewhat darker than on the fabrics listed above.

There are three advantages to this approach. First, when the material is being transported or stored it can be rolled up neatly which protects it. Second, the material is hung in such a way that it naturally sways into a perfectly vertical position because of gravity. This helps offset any issues with leaning or asymmetries in the frames. The perforated material (that allows for light to pass through) aids in the use of infrared tracking devices.

The largest drawback is cost. Depending on quality, location, and source, it can cost $300-$800 dollars per roll. Additionally, it cannot be shortened for travel and therefore causes a problem with storage and transportation.

iv. Acrylic Sheets

Frosted acrylic sheets would have two advantages in this project. First, it would provide the best surface for creating a touch-based user interface. Second, it produces a clean, flat, high-quality image from the projector.

However, there are some downsides. First, the cost would be incredibly high. To create screens at roughly 10 feet by 6 feet, three pieces would be needed and at least one would need to be cut (a non-trivial process at this size). This could easily lead to hundreds of dollars in acrylic. Second, the pieces would be difficult to safely transport from site to site. Third, placing them together would cause seams between the pieces which can easily distort the projected image.

v. Rolled Plastic

Plastics companies produce rolls of thin plastic sheets that are stiff enough to provide a reactive touch surface and a quality projector image. However, when tested, these materials had a number of downsides. The structural "memory" makes it hard to remove curling from the plastic. Adding grommets to hang the plastic sheets proved difficult without damaging the plastic. Finally, the standard sizes of the rolls are too small and custom orders are cost prohibitive.

4. Input Approaches

Part of the Smart Classroom is developing interactive interfaces for the software. Several were tested. Some were more successful than others.

a. Overview of Input Approaches

The ability to create 10-foot wide touch screen systems certainly exists. However, it proved difficult to create a version that met all the goals of the project (see Section 1). Commercial products were quite expensive and required a significant increase in technological complexity. New approaches were implemented, but the details of implementation were not successfully met within the scope and schedule of the project. However, an approach is nearing completion and, once ready, will be released as an open source solution.

The following sections briefly overview the input systems or approaches implemented and tested in the project.

b. Keyboard and Mouse on Table

The simplest approach was to use keyboards and mice in combination where appropriate for the software use-case. Initially, wireless devices were used but in cases with multiple devices signal conflicts sometimes arose. In those cases, USB extending cables provided quite successful.

c. 3D Mouse

A 3D mouse is a handheld device that can operated similarly to a laser pointer. But, instead of shining a light it controls the computer's mouse. This allows the user to control a mouse while standing, walking around, and across multiple displays. In testing this device was quite practical. It was especially useful when one person was using the Smart Classroom to present visual information to a group of viewers.

d. Touch-Enabled Mobile Web Browser (Tablet or Phone)

As part of the project, we developed interactive software. In testing different interfaces, we developed software that turned any touch-sensitive mobile device (phone, tablet, or laptop) into a control pad. Using a web-based front-end on the tablet, web commands were sent to a specific IP number and port on a server that could then send commands to the software developed for the project. A more advanced version of this tool could allow generalized control of a computer system and was both useful and impressive when tested on user groups.

e. Kinect Stereoscopic Camera

While there are other systems with comparable abilities, the Kinect stereoscopic camera allows for a range of visible and infrared light tracking. Using software libraries and custom-created tools, body tracking made it possible to make the Smart Classroom controllable by hands or body motions.

i. Open Source Software

The KinectV2MouseControl is an open source tool for converting Kinect hand motion tracking into a 2D mouse controller for a Windows PC. We tested this and found that while useful, it was draining on the system resources and would potentially slow down other software running on the computer. An additional issue is that most desktop computers only allow one mouse cursor at a time. But, in an environment designed to have multiple people near each other, the system sometimes had trouble differentiating who was controlling the mouse.

https://github.com/TangoChen/KinectV2MouseControl

ii. Commercial Software

There are systems available that convert the Kinect camera into a touch wall sensor. Products made by Ubi, Intuiface, and Touchless Touch all offer the promise of Kinect-based touch screen systems but none provided the kind of multi-touch interface the project intended. The primary issue was with limitations on the size of the screen or surface that could be used. While there are commercial solutions available to support an environment the size and shape of the Smart Classroom, they are all custom built and extremely expensive relative to the aims of this project.

No commercial solution was found that addressed the goals outlined in Section 1 of this report.

iii. Custom Built Software

As part of developing experimental use cases, we developed software that could make use of the Kinect's abilities. Controlling the mouse, scaling objects, and selecting information were made possible by software developed as part of this project. Using arm and hand gestures users could control various aspects of the software. It worked better than the mouse software outlined above, but still suffered from the issue of multiple users causing conflicts.

f. Leap Motion Device

UltraLeap is a company that produced physical devices for tracking body motion, primarily hands. The Leap Motion is a device for tracking hand movement. This software is useful for using touchless interaction with a computer system when the users hands will be quite close to the screen. Testing of this device indicated it was good for single users when interacting directly with one screen but did not scale to multiple users.

g. UltraLeap 3Di

Also made by UltraLeap, the 3Di is a more advanced system that tracks hand motions but from further away and with greater accuracy. In testing this device offered a better range of mobility and distance from the projection screens. One target application for this hardware is a touchless kiosk. That same approach appears to work in the Smart Classroom. Users can stand further from the screen and use larger gestures while able to view at least three screens at the same time. This device seems like a fruitful approach, though it does have the same downside of only supporting one user interacting at a time.

h. Infrared Systems

A common approach to touch systems is to use infrared light. Cameras filter out the visible light leaving only infrared energy. In a touch-based system the light is bounced off the users' fingers through glass into a camera. This version is not applicable to the approach taken in the Smart Classroom. Instead, having users hold small infrared lights (about the size of a fingertip) and tracking them with the camera. Software converts the images into black and white data of "blobs" which represent where users are touching the screen with their lights.

There are two important advantages to this approach. First, it is relatively cheap to produce with components available for retail purchase and open source software libraries. Second, it allows for a true multi-user experience since a number of these "blobs" can be tracked simultaneously.

i. Commercial Projector-Based System

Some projectors have an infrared tracking system as an optional add on. A camera is connected to the projector to look at the screen and infrared "markers" are used to indicate touches. The NEC version of this system was tested with the NEC projectors used in the Smart Classroom setup. While the tracking was generally good, the "markers" require a hard surface to press against in order to activate. This was incompatible with the fabric screen materials. Additionally, the cameras in this system are designed to operate from the same side of the screen as the projector. However, in the Smart Classroom, the user's infrared light is on the opposite side of the screen from the projector. This caused issues with the sensor accurately tracking the "marker." Overall, there were drawbacks that could be solved for. However, at a cost of over $300 per screen and the significant technological requirements to link them together for the Smart Classroom, it was not a practical approach.

ii. Custom Built System

In order to overcome these issues, we began developing a system based on the same principles but overcoming the limitations. Using off-the-shelf components, an infrared light tracker was built. An infrared camera is combined with a visible-light blocking filter. This camera is capable of seeing infrared light coming through the fabric screens in the prototypes. Toy "finger lights" were altered with infrared LED bulbs so that users could easily touch the screen and control whether the light is on or off.

Software was written in Python and C# that leveraged the OpenCV 2 open source image processing libraries. A basic prototype was created. A fully functional version is still being completed by the Institute for New Media Studies. Once the approach is developed and integrated into a multi-sensor suite (for multiple screens – see Section 6) it will be released as an open source tool for similar applications.

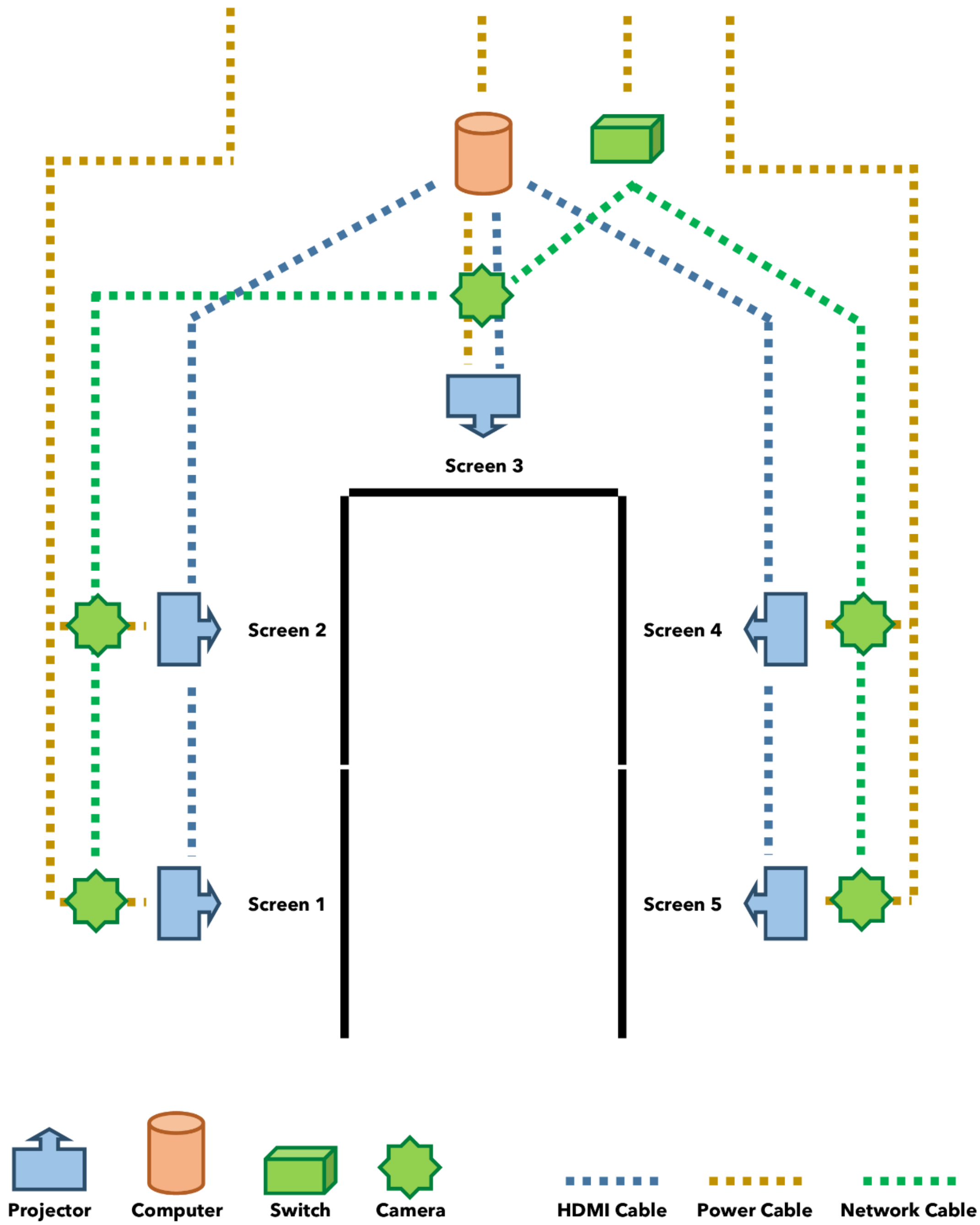
5. Computer Control System

For illustration purposes, this section uses the Five Screen Rectangle Room layout (see Section 10). However, this is only one example to help visualize components and concepts. It can be modified to work with any of the designs outlined in this document (see Section 10).

There is much variability in the specific computer hardware used for a platform like the Smart Classroom. While the options will continue to improve, the correct choices will come down to the specific implementation of a Smart Classroom and the budget constraints.

In this prototype, the balance of simplifying technology for the sake of user experience indicated a single, large computer capable of powering all six projectors at once. A Windows 10 computer with ample memory and processing power was built with two GTX 2080 graphics cards bridged together to provide the power and available video ports. USB ports, wired network, and wireless network connections are used to support the various software and peripherals for the project.

On the next page is a diagram of the Smart Classrooms devices, wires, and screens. Sections 6, 7, and 8 use this diagram.


Screen 3
Screen 2
Screen 4
Screen 1
Screen 5
Projector
Computer
Switch
Camera
HDMI Cable
Power Cable
Network Cable

6. Network Design

For illustration purposes, this section uses the Five Screen Rectangle Room layout (see Section 10). However, this is only one example to help visualize components and concepts. It can be modified to work with any of the designs outlined in this document (see Section 10).

In order to implement the custom IR tracking system, each screen needs an IR camera and lens. Those cameras will also require a miniature computer to process the data and send it back to the main computer. Ideally these computers would be Raspberry Pi devices. National shortages have highlighted the need to keep the design hardware agnostic. The IR camera tracking software is being written to open standards that should work on a range of small computing devices.

A switch is necessary to handle the local network traffic and feed tracking data to the main computer. The switch could, optionally, be connected to the internet for accessing information from outside the Smart Classroom and providing that access to each individual device as necessary.

7. Power Design

For illustration purposes, this section uses the Five Screen Rectangle Room layout (see Section 10). However, this is only one example to help visualize components and concepts. It can be modified to work with any of the designs outlined in this document (see Section 10).

Surge protected power strips run to sets of devices. The switch, main computer, and projector #3 each have their own power strip plugged into the wall. Projector #1 camera #1 share a strip, projector #2 and camera #2 have their own, as do projectors #4 and #5 with their respective cameras and mini computers.

8. Cabling Design

For illustration purposes, this section uses the Five Screen Rectangle Room layout (see Section 10). However, this is only one example to help visualize components and concepts. It can be modified to work with any of the designs outlined in this document (see Section 10).

Cables are best run along the ground, through the frames. Plastic conduit tubing is a cheap way to organize cables into bundles that run to the same places. The diagram shows where overlapping data and video cables allow for conduit to bundle wires in ways that will make assembling and disassembling the Smart Classroom easier and its use safer.

9. Storage and Transportation Options

A traveling project like this needs the ability to be stored and shipped safely. A significant portion of the project cost goes to cases and portability products.

The most fragile elements are the six projectors and the main computer. The best option for these items is Pelican hard-sided cases with custom cut foam inserts. To ensure the foam is cut in the best way, we purchased solid foam and cut it ourselves. This way the seven cases fit their respective items correctly and safely.

For the metal components of the frames, a convenient and economical solution was 6-foot long canvas bags originally designed and sold as storage bags for outdoor umbrellas to go with patio furniture. The bags are long enough and contain enough space to hold nearly all the metal components for one screen. This way there are six bags for six screens. This not only makes storage and transport easier, but clearly identifies which parts go to which part of the Smart Classroom.

Many options for transporting cables, small parts, and networking components were considered. The most economical and easiest are simple storage totes with rubberized bottoms. Within these larger bins, smaller boxes can be used for organizing materials with Velcro cable straps and zip lock bags used to keep individual items within boxes in their correct places.

10. Experience Design Options

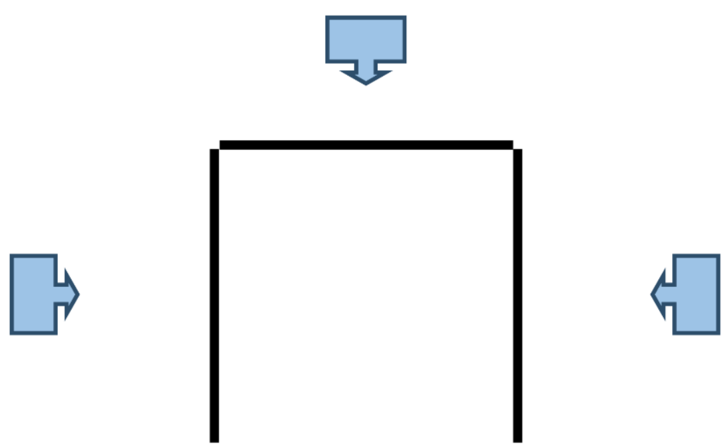
There is a range of possible Smart Classroom layouts available with the module approach taken in this project. Below are the primary items identified as offering the most potential use.

One Screen

A single screen is easy to assemble and cheap to produce. The best application is for a single presenter or for having learners use the system one at a time (single user experience).

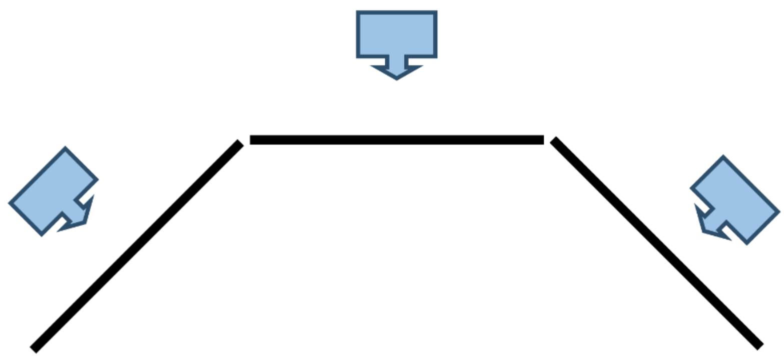
Three Screen Square Room

This is ideal for creating a more immersive experience for up to 10 people depending on the peripherals used. The fourth side being open makes it easy for learners to move in and out of the area.



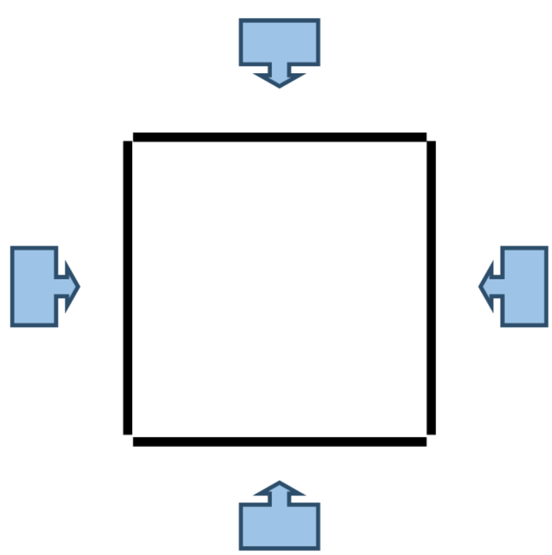
Three Screen Trapezoid Wall

With a larger group of people or a larger working space this approach creates a more expansive view and allows people to stand further back and see the information on all three screens at the same time. Using three screens provides useful presentation models such as introduction, body, conclusion parts.



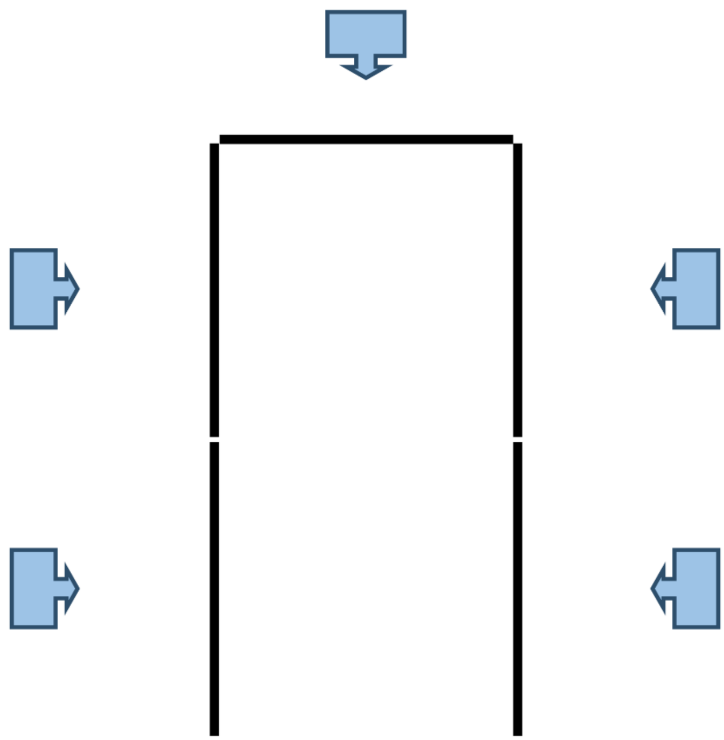
Four Screen Square Room

This is ideal for creating a more immersive experience for up to 10 people depending on the peripherals used. The fourth side being closed creates a cohesive environment separated from learners outside the Smart Classroom.



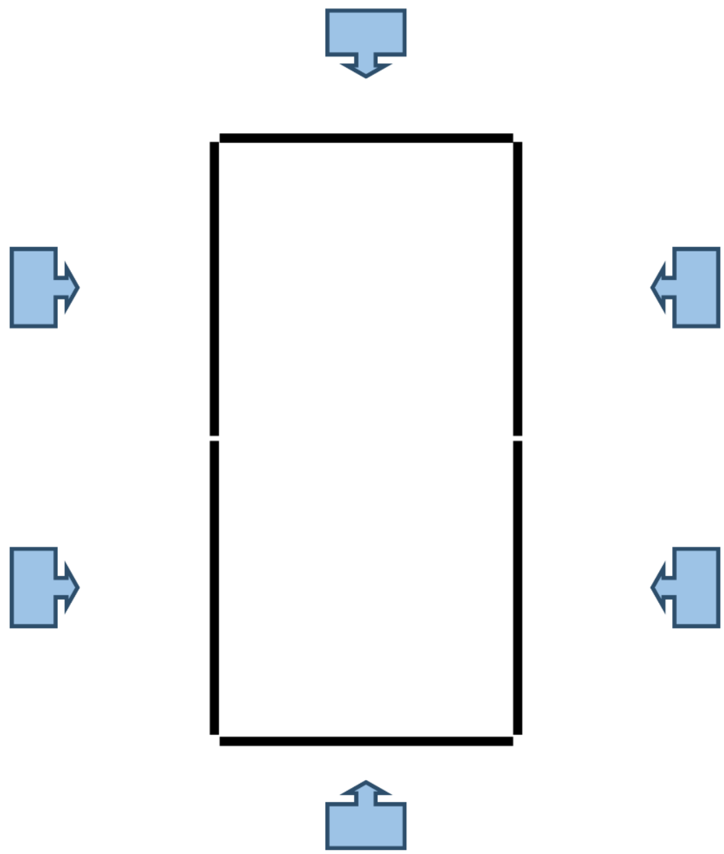
Five Screen Rectangle Room

We labeled this layout the horseshoe. It enjoys the benefits of the three screen square room with double the available space. The increased space allows more learners to participate and a broader range of content across five screens.



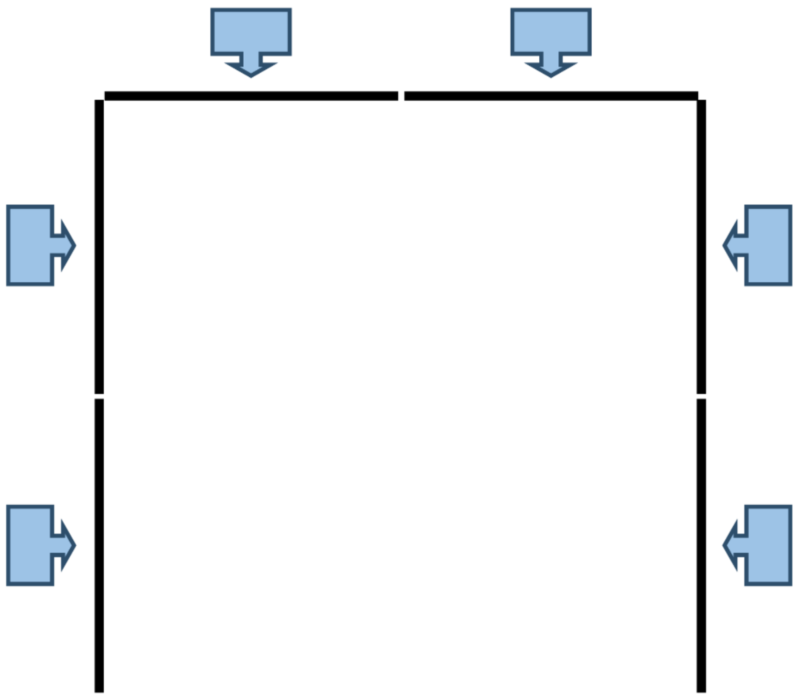
Six Screen Rectangle Room

It enjoys the benefits of the five screen rectangle room. The sixth side being closed creates a cohesive environment separated from learners outside the Smart Classroom.



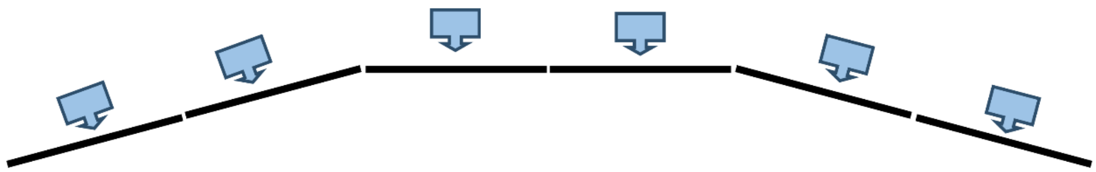
Six Screen Square Room

Utilizing all six screens, this approach is similar to the three screen square room but double the screen space and four times the space for learners. This layout maximizes the amount of space and screen for a given learning environment.



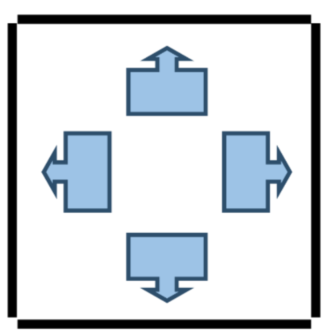
Six Screen Vista

If space allows, this 60 foot wide wall allows an expansive view of data and learning content. In order to maximize the emotional and visual effect, screens 1, 2, 5, and 6 should be slightly curved in by about 15 percent. This will create a more immersive effect that can be viewed up close or from a distance with line-of-sight to each screen from the center.



Four Screen Display Cube

For smaller presentations or interactive learning opportunities for larger groups in a larger space, this approach creates a cube where the learners are on the outside of a box covered in learning content.



11. Future Options and Alternatives Not Tested

Some items that might be considered for future development of the project include:

a. Plastic conduit tubing as noted in Section 8
b. Wheels under the screens would allow them to be moved and finely adjusted more easily. Screwed in wheels could also be used to adjust the height of the screens more accurately
c. For cost and safety reasons, this prototype relied on short throw projectors sitting on or near the floor. A version of the Smart Classroom with a larger budget could design the frames to suspend the projectors from the ceiling or top of the screens. This would allow for the empty space of the frames to be utilized as a front-projection screen setup or for two-sided learning opportunities. It may also open more floor space in confined rooms. However, this would require strong and stable frames which may not be possible within the goals outlined in Section 1
d. Using wing nuts instead of hex nuts would make it easier to assemble and disassemble the Smart Classroom. But they cost 4-5 times as much as the hex nuts