2006-884: USE OF PHYSICAL SIMULATION AND A COMMON PRODUCT THROUGH A SERIES OF COURSES TO ILLUSTRATE INDUSTRIAL AND MANUFACTURING ENGINEERING PRINCIPLES

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Use of Physical Simulation and a Common Product through a Series of Courses to Illustrate Industrial and Manufacturing Engineering Technology Principles

There has always been a great debate in educational circles as to how students learn and to what is the best approach to delivering education that can be applied. Problem Based Learning[1], Action Learning[2], Hands-on Learning, or Hear-See-Do approach, coupled with traditional classroom lectures and assignments have all been used with varying degrees of effectiveness.

In the field of Engineering Technology, most learning environments stress understanding of and applying various principles to solve problems and to make improvements. Savery and Duffy in their "Problem Based Learning: An Instructional Model and its constructivist framework"[1] state: "It is said that there is nothing so practical as good theory. It may also be said that there's nothing so theoretically interesting as good practice." Marquardt[2] in his "Harnessing the Power of Action Learning" states "...all forms of action learning share the elements of real people resolving and taking action on real problems in real time and learning while doing so."

This is what our educational approach to engineering technology education has been all about. To address these issues, we create laboratory problems, institute engineering coop programs, and do capstone projects, all to get students exposed to "real world problems". These are all excellent approaches and should be applied wherever practical. There are problems associated with this approach, however. Some problems with all these approaches include difficulty finding co-op opportunities, judging results from vastly different projects and contexts, and not having proper framework of understanding to make these assignments truly worthwhile.

Our approach has been to develop a simple product, use that product (with several variations) through a series of courses that illustrate various principles of Industrial and Manufacturing Engineering Technology to provide a context and a learning environment that both challenges and involves the students. This comes as close as possible to duplicating what they will encounter once they enter the real-world workforce.

The product is K'nex plastic construction parts which can be assembled into any variety of products. We chose to develop the "Wagons-R-Us" product line (see appendix A and Figures 1B to 4B in appendix B) in which a series of wagons have been designed and built and are used as a model of activity through a series of courses.

The K'Nex parts are widely available, reusable, relatively inexpensive, and can be configured into any number of products. The variety of components available allows the complexity of the problems to increase over time as the student advances from one course to the next. Couple this product with the use of Creform building materials[3] to create three-dimensional, life-like workstations and you have the basis for the construction of a simulated factory environment that can mimic what a student could expect to see once they enter the workforce.

In this case, the principles to be learned and the project used to teach these principles can be controlled, monitored and measured in such a way that constructive feedback can be provided, comparisons made and real learning can take place.

The Product

The first step was to obtain the K'Nex and decide upon and build a series of related products. In our case it is the Wagons-R-Us product line. (See Appendix B Figures 1B to 4B for pictures of various models). The prints for these products were then drawn, exploded into a model Bill of Materials and a part numbering system created (see appendix A). This information is the baseline that is threaded through our series of classes.

K'Nex parts can be obtained from http://orders.knex.com at a modest cost. It is suggested that enough parts for at least 50 units of production be purchased. It is also recommended that other similar parts not used in the construction of your product also be purchased. For example, there are various size tires available and it is very illustrative to buy several sizes so when a stockroom is set-up and a student needs a "tire" there are several to choose from, thereby illustrating the need for a part-numbering system. The product can be as simple or as complex as desired. See attached parts lists and pictures for illustration (Appendices A & B).

The Courses

Currently, the K'nex product is used through three main courses in which the major focus and class project centers on the K'nex product: IET 101 Work Methods Analysis and Improvements, IET 111 Work Measurement Techniques and IET 130 Lean Manufacturing. The courses are taken in this sequence and principles are illustrated, reinforced and built upon as the student progresses through the series. Analysis of the content and intent of each course is as follows:

IET 101 Work Methods Analysis and Improvements.

In this course the concepts of a Process Flow chart and a Process Flow Diagram are introduced. The students are introduced to the least complex Wagons-R-Us product (see Figure 1B, appendix B) and provided with the prints, a Bill of Materials and the Part Numbering system.

They are placed on teams consisting of four to eight students and given a process layout and production routing for producing a wagon. Production rules are established and these rules must be followed for the first trial run.

Each student team's assignment is to run the process and produce as many wagons as possible in 30 minutes, using the pre-set layout, Bill of Materials and production routing and the resulting process flow path. A productivity index is established (parts per operator per 30 minutes) and this Index is tracked throughout each simulation run during the entire course.

The concepts taught during the class in addition to Flowchart/Flow diagrams are Pareto Analysis, Cause and Effect Diagrams, Brainstorming, how to determine the best solution, production line theory and "selling" your ideas.

The class Project is to work on the layout, process, production methods, etc. using the analysis concepts and tools taught with the goal being to increase productivity to the maximum.

Teams work in secret competition against other teams, with the objective to see which team can achieve the highest productivity. There are three formal production runs of the process (including the initial run) and a final run the last class period.

A formal report by each team is made prior to the final production run in which they summarize the results of each trial, talk about problems encountered and solutions devised and make a projection for the final run output and Productivity index. Each team will make their presentation and then each team will execute their plan.

This is the first time the other teams will have the opportunity to see other the team's the process. It is interesting to observe how different groups will attack the same problem. Some have simple, stock solutions; others will have created elaborate fixtures and line balancing techniques. The runs are video taped and are analyzed after completion. The teams share lessons learned.

As instructors, we become more of a coach/ facilitator than a teacher during the lab activities. It is intended to be the students' project. This follows what Savery and Duffy propose: "The Teacher must not take over thinking for the learner by telling the learner what to do or how to think, but rather teaching should be done by inquiring at the "leading edge" of the protégé's thinking."[1]

It is important to note that there are no "right" answers, just "better" answers. The results demonstrate an acute awareness of progress. Most teams do not even complete one wagon during the initial run but progress as far as fifteen wagons per person during the final run. Most teams will average between 8 to 10 wagons per person.

Besides the techniques taught, the students learn how to work together as a team, make work assignments, and put together a formal presentation in which all members must participate. Most teams get caught up in the competition and actually have FUN while learning something. To leverage off this learning, the next class in the series starts where this class project ends and uses it as a starting point for a whole new set of skills.

IET 111 Work Measurement Techniques

In this course we focus on effective work motions, proper work methods, basic industrial ergonomics, Time study and Work Standards calculations, Introduction to MTM and Motion Kaizen.

The same basic wagon used in IET 101 is used, but some modifications to the process have been made. Workplace holding fixtures have been designed and built (see Figures1D through 5D appendix D). Workstations to hold these fixtures have also been built out of Creform[3]. These stations allow for a progressive build-up of the wagon as it progresses from station to station. This allows students to use an assembly line concept.

The class projects here focuses on workplace organization, effective work methods and productivity improvement. The class is broken into four teams, one for each station and their assignment is to create the “perfect workstation” using the concepts taught in class.

They must time the method they used in IET 101 for each sub-assembly and use this as the baseline to measure improvements. They then spend the quarter working on workplace improvements, using different work measurement techniques and measure their productivity improvement.

They can calculate the Productivity Index for each station by a variety of means taught in the class (Time study, MTM, and Motion Kaizen). These results are compared to the baseline numbers and a percent improvement is calculated. To further enhance the reality of this simulation, the individual groups must work together to create an assembly line and strive to achieve the best labor balance.

The final project is running the assembly line for the instructor, going over the work methods for each station comparing them to the baseline and showing the operator work instructions posted at the job.

To enhance the experience, the students are encouraged to brainstorm as many good ergonomic and effective methods/motion examples as possible. These can be roughly built out of K’nex or other material found in our lab, but our Industrial Engineering Technology Lab Technician must build the production equipment. He represents the Maintenance Department.

The goal of our lab is not to create production line workers (though we wish them to understand what the production operator experiences as a result of their decisions) but engineering technicians. They must communicate their ideas to maintenance through models, sketches, and/or verbal communication. They need to get their jobs scheduled and completed on time at an economically justifiable cost. The use of the K’nex Wagons-R-Us product and the transformation from strictly speed, to thoughtful, efficient production can be seen.

The practical lessons learned from the lab amplify the concepts taught in the classroom and by using the same product, more effective assessment of the results can be made, not only by the instructor, but also by the students themselves. Previous class results can be shown and critiqued. Mistakes can been seen and learned from. This is where Action Learning takes place.

IET 130 Lean Manufacturing

In this course the concept of Lean Manufacturing is explored in detail. Such topics as Lead Time Reduction, Waste Identification and Elimination, Value Stream Mapping, Containerization, Standardized Work and Takt Time, Set-up reduction, One Piece Flow, Work Cell Design and Kanban (or Pull Systems) are covered in concept and practice.

The lecture covers these topics; the Lab puts them into practice. We take the basic wagon used in IET 101 and IET 111 and add another model, which is similar, but different enough to require a separate subassembly build process and each model now has an optional top added, which also requires a separate build process (see figures 2B through 4B in appendix B).

To enhance the realism of the lab exercise, parts of the wagons now require fabrication in plant. We have designed and built two types of machines that simulate production machines found in a factory.

A C.A.T. (Controlled Access Timer) Box which requires students to load K'nex components onto a fixture, place them in the C.A.T. box, and hit a timer to "process" the parts (see Figures 1C and 2C in Appendix C). This would simulate any "load and leave" machine that could be found in industry such as a molding machine, CNC machine, etc.

This requires the students to determine the number of each component required for each product and based on the customer demand, determine if the demand can be met or if improvements must be made. Using a timer with wide range of possible elapsed times, the cycle time of the C.A.T. Boxes is preset by the instructor.

This further complicates the process by allowing unbalanced cycle times among different "machines" and cycle times that are longer than the required Takt times. Improvement options run from methods improvement, tooling improvements, or acquisition of more machines. The most productive solution is emphasized.

The second piece of equipment designed is affectionately named a "Parts Puker" which simulates an injection-molding machine, an extrusion line or some similar continuous process (see Figures 3C and 4 C in Appendix C). Here the students are required to place the proper tooling on the machine, load the proper components onto the machine, and cycle the machine. The machine then "produces" (spits out) the parts at a predetermined rate, which, as with the C.A.T. Box, can be adjusted by the instructor.

The students once again must measure the output of the machines and compare them to the customer demand and ensure that the demand is met. In this case the “customers” are the assembly stations which were developed in IET 111, now reconfigured into a work cell, and the sub-assembly stations where new components are made. If the demand cannot be met, improvements to the fabrication area must be made.

Improved production techniques, which could include better packaging from suppliers, better loading methods, increased machine speed, or extra machines, are implemented. Again, the most productive solution is stressed. The assembly stations are the ones designed in IET 111, but are continued to be improved, arranged in a work cell with the staffing determined by the customer demand.

In this course, the entire class is put on the project of creating a Lean Manufacturing Organization that can produce four different (but similar) wagons on demand based on a projected forecast. Generally the forecast is 60% product A, 20% product B, and 10% A with a top and 10% B with a top (see figures 1B through 4B in Appendix B).

We have enough equipment to run three C.A.T. boxes, three Parts Pukers, two assembly cells and as many sub-assembly areas as needed. The customer demand can be varied from 1 piece every 30 seconds up to one piece every two minutes. This allows us to accommodate teams from 4 to 15 people, depending on class size. By building more equipment, we could have larger teams, but due to the content of this class, we try to keep the maximum size at 15.

Again, in this lab the students are familiar with K’nex, but now must deal with more wagon designs and more complexity in working together. Students are generally assigned to one of the three production areas (fabrication, sub-assembly, or assembly) and they must also deliver the parts based on a pull system. This allows them to design a pull system, implement it and run it. This comes as close to duplicating a full manufacturing facility as one can considering space and cost limitations.

The course project is to set-up and run the cell the last class period with the actual production mix based on random pulls generated by the results of a 10-sided die roll which allows us to make use of our 60%-20%-10%-10% production mix. The customer demand time will determine how long the simulation will run. We like to run at least 30 parts or ½ hour for the simulation. As done before in previous classes, the IE Lab Technician must build any improvements suggested by the students. The results are video taped and comparisons with other teams can be made. The concept of using the same product through the series of classes allows the students to see how the concepts taught in this and the prior courses are related to each other, and allows the students to see the progress they have made in their learning journey.

The students who then take the capstone course and go out and do a project in industry are better able to function at a higher level and transfer their learning context into a new environment.

Future Developments

The courses described have been running for the past six years and have proven to be very successful. Feedback from students who have taken the courses (see appendix E for data and explanation) has been extremely positive.

Eighty five percent of the students who have taken the classes have rated the lab component to be a positive experience.

Comments from companies who use our students during their industry capstone projects, hire our graduates and four-year schools to which they enrolled to pursue their bachelor degrees have been very favorable. Though these responses have been the result of conversations with said institutions and have not been formally documented (though we are working toward formalizing such data); it reinforces what we have done, and has encouraged us to see how many more courses and contextual learning's could be modified to include use of the K'Nex parts.

Currently, we have added the Wagon-R-Us products to our IET 115 Production and Inventory Control Class. The Teams use the wagons to construct Bills of Material, production schedules, part numbering and Routing Systems. This course, taken in conjunction with the above courses, enhances learning.

Another course we are working this product into is IET 207 Computer Simulation. In IET 130 we create a physical simulation of a work cell and execute it. In IET 207 we have the students work with the students in IET 130 and complete a computer simulation of the production cell that has been created. This allows the students to gather better data over longer periods of time and predict how the actual cell would run. This has proven very popular, but we are having some challenges trying to schedule and coordinate student's schedules to allow this collaboration.

Wagon-R-Us products and information are also used to a lesser extent in IET-135, Manufacturing Cost Analysis. In this course the costing of the Production Routing and Bill of Materials is featured.

Over all, using the same Wagons-R-Us product line information in several different courses ties these courses together and cause students to see the relationship among topics taught in these courses. The labs and homework in these courses cause students to see the relationships among different parts of a manufacturing a operation.

In addition, we have been faced with the challenge of how to offer these types of courses as distance learning courses, but have been stymied by the lab content. Working with Dr. Jim Houdeshell and his Distributed-Hybrid Model of delivery[4], we feel we have an option to provide this instruction on-line with satellite lab stations strategically located throughout the surrounding counties.

To keep the labs consistent and easy for a facilitator to monitor, this use of consistent, readily available and relatively inexpensive materials allows us to provide such an opportunity. This is something that any school can set up rather quickly and easily and provide their students with a consistent, hands on activity to teach the concepts and allow transfer of learning's to a broader context.

SUMMARY

In summary, we have taken a very basic, but flexible construction material, K'Nex, and by use of clever design have created a structured, applied and linked learning environment. By having a common product weaving its way through several courses, students learn how the different subjects being taught in different classes are related. It is as if the student was hired by a company and is moved through orientation and training through various departments and assignments, linked by a common product. This is what they will experience when they enter industry, but we are able to control and monitor their learning and assess the results of our instructional efforts on a more consistent basis.

Appendix A

WAGONS - R - US

PART AND ASSEMBLY NUMBERING SYSTEM

GENERAL NUMBER FORMAT

X - YYY - ###

The X, is used to identify the general type of item being described. The items and their descriptions are:

P = Individual Part
S = Sub Assembly
F = Final Assembly

Part Number Format

X - YYY - ###

The first Y, is used to identify the general type of part being described. The parts and their descriptions are:

P = Flat Panels
R = Rods
T = Tires
C = Connectors
H = Tire Hubs
L = Locks
K = Knobs

X - YYY - ###

The second and third YY, is used to provide information to identify a specific part. Specific information to include is the part color used to identify the part upon sight. Color descriptions to use include:

WH = White
BU = Blue
YE = Yellow
GE = Green
BA = Black
RE = Red

PU = Purple
GA = Gray
TA = Tan

X - YYY - ###

The three number positions (###) on the right are used to provide identifiC.A.T.ion numbers to parts that have the same descriptions in the first four positions from the left. For example, small, medium and large tires are:

P - TBA - 001 P = Individual Part - T = Tire, BA = Black - 001 = small size
P - TBA - 002 P = Individual Part - T = Tire, BA = Black - 002 = medium
P - TBA - 003 P = Individual Part - T = Tire, BA = Black - 003 = large size

Where there is only one type of part for a given description the number "001" will be assigned. For example, there is only one length of yellow rod. The number for this part is:

P - RYE - 001

SUB ASSEMBLY NUMBER FORMAT

S - YYY - ###

The three "Y" positions are used to identify the type of subassembly. The first position on the left is used to denote the type of sub assembly. The letters used are " B" for wagon bed, "S" for side rails, "E" for side rail extensions, "H" for hitch, "P" stands for panel, and "A" for axles. The second and third positions denote additional information to denote the main type of material the product is constructed from. "RO" is used to denote rods, and "PA" to denote panels. The types of subassemblies and their descriptions are:

ARO = Axle, using rods
BHP = Bed and hitch, panel bottom
BHR = Bed and hitch, rod bottom
ERO = Extension, using rods
ROE = Rod extension, using rods
HRO = Handle, using rods

The three number positions on the right are used to provide identifiC.A.T.ion numbers to sub assemblies that have the same descriptions in the first four positions from the left. For example, there are two existing axles. One for wagons and one for the tractor. Their sub assembly numbers are:

S - ARO - 001 = Axle, using rods, wagon

Where there is only one type of sub assembly for a given description the number "001" will be assigned. For example, there is, at present, only one type of hitch. The sub assembly number for this item is: S – ARO – 001.

FINAL ASSEMBLY NUMBER FORMAT

X - YYY - ###

The three "YYY"s are used to identify the type of final product. The order of description for wagons is "W" for wagons, the "F" or "R" to denote the type of bottom, and "N" , "R", or "P" to denote the type of bottom, and "N", "R" , or "P" to denote the extension option.

The three number positions on the right are used to provide identifiC.A.T.ion numbers to final products that have the same descriptions in the first four positions from the left. At present there are no examples of this occurring. Where there is only one type of sub assembly for a given description the number "001" will be assigned.

The existing product names and their part numbers are listed in the following section.

PRODUCT FAMILIES

Product Names:	Finished Product Part #:
Wagon, flat bottom, w/ no rod side extensions	F-WFN-001
Wagon, flat bottom, w/ rod side extensions	F-WFR-001
Wagon, rod bottom, w/ no rod side extensions	F-WRN-001
Wagon, rod bottom, w/ rod side extensions	F-WRR-001

Appendix B

Wagon Models

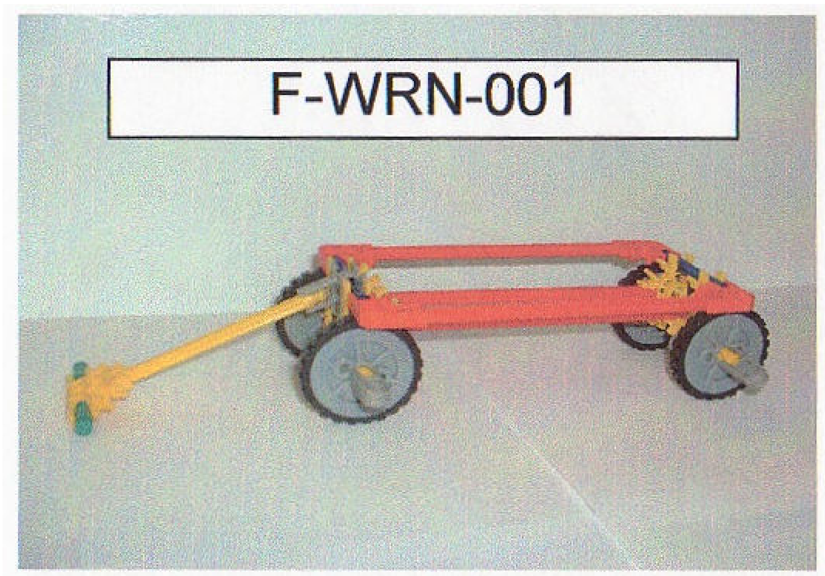

Figure 1B
This part number makes us 60% of the product mix in IET-130

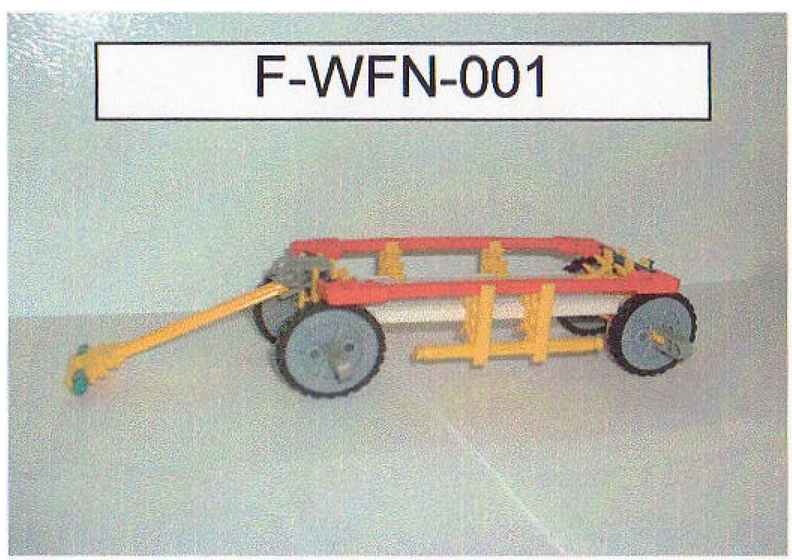

Figure 2B
This part number makes us 20% of the product mix in IET-130

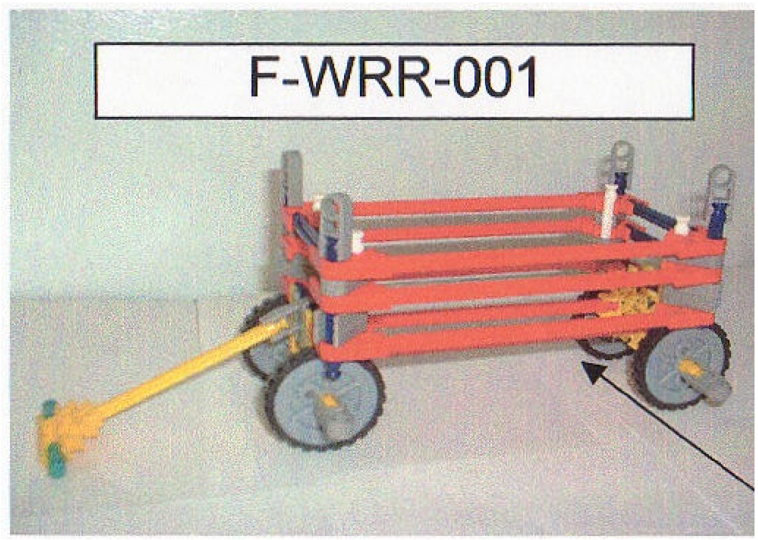

Figure 3B
This part number makes us 10% of the product mix in IET-130

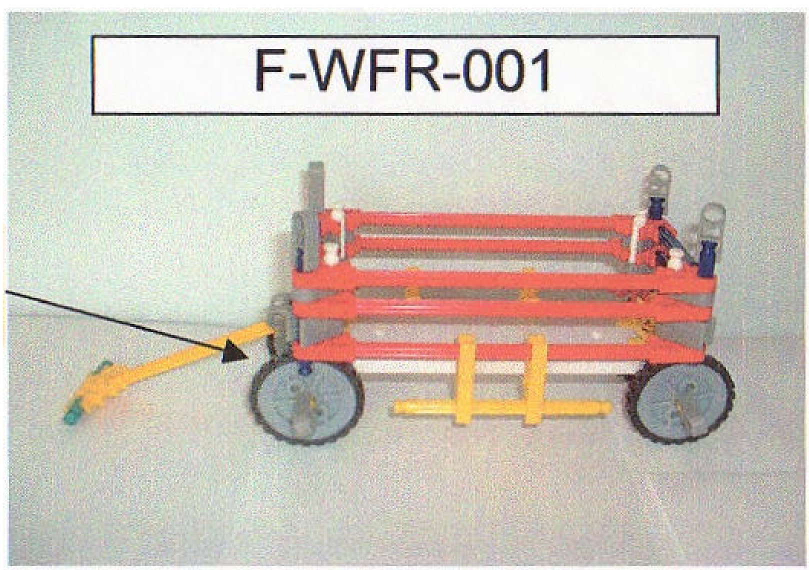

Figure 4B
This part number makes us 10% of the product mix in IET-130

Appendix C

Production Simulation Machinery

Controlled Access Timer (C.A.T.) Box

Figure 1C

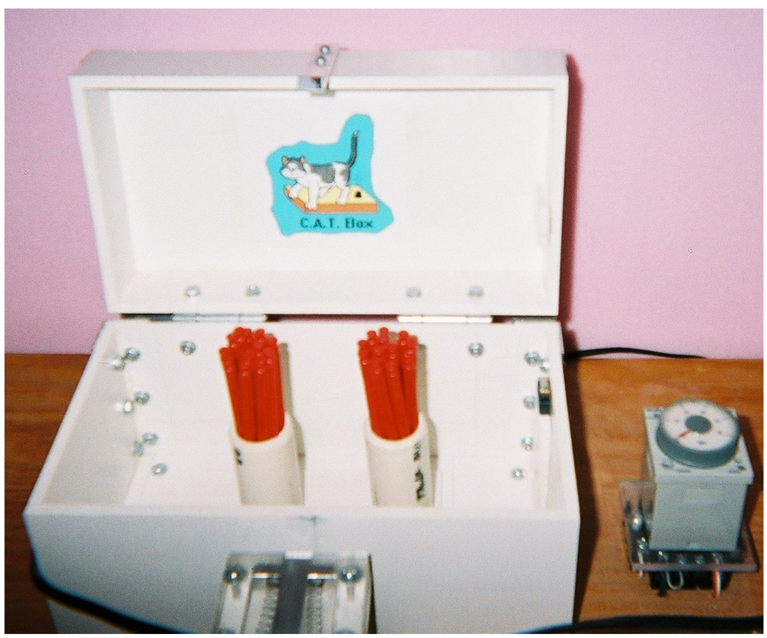

Figure 2C

Parts Pukers

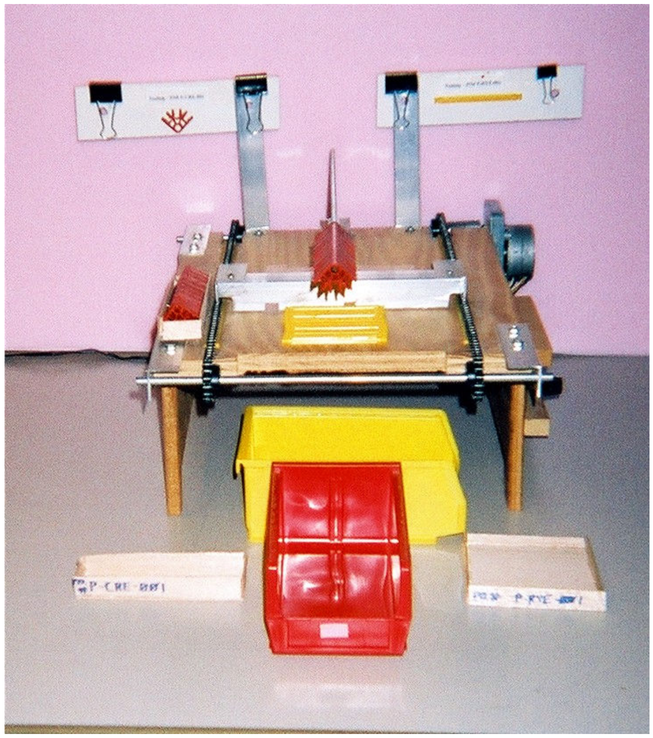

Figure 3C

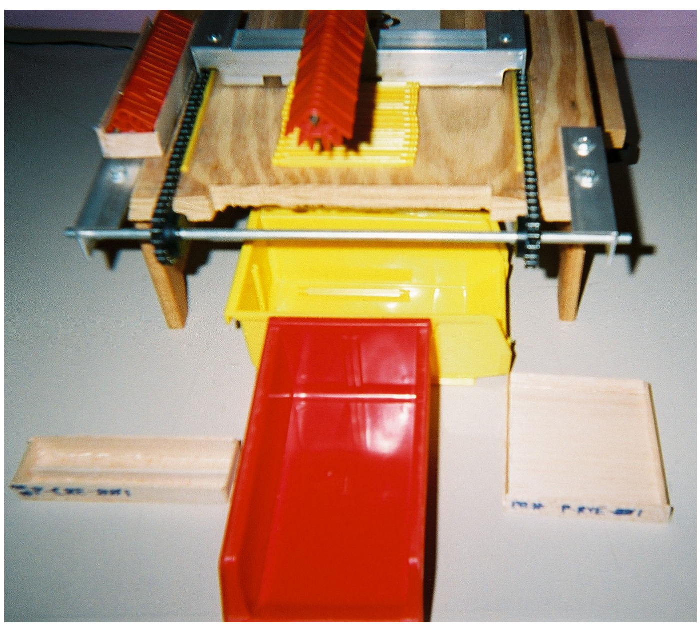

Figure 4C

Appendix D

Fixtures and Creform Work Stations

Figure 1D

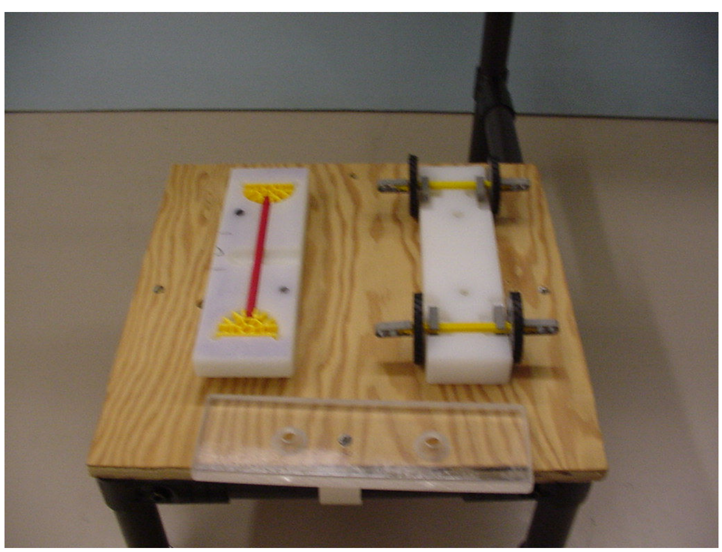

Figure 2D

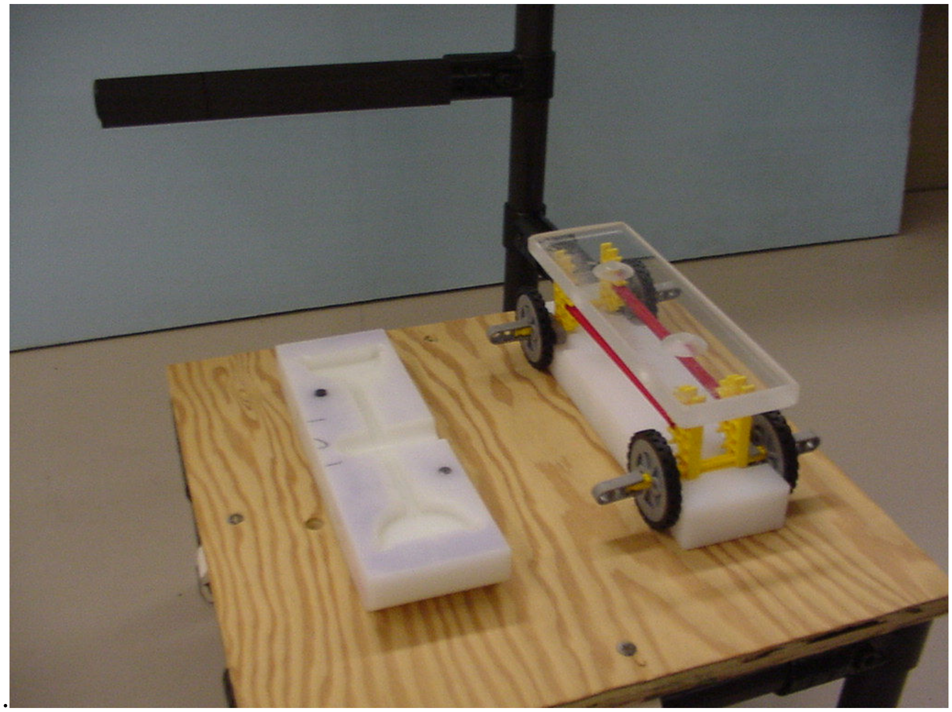

Figure 3D

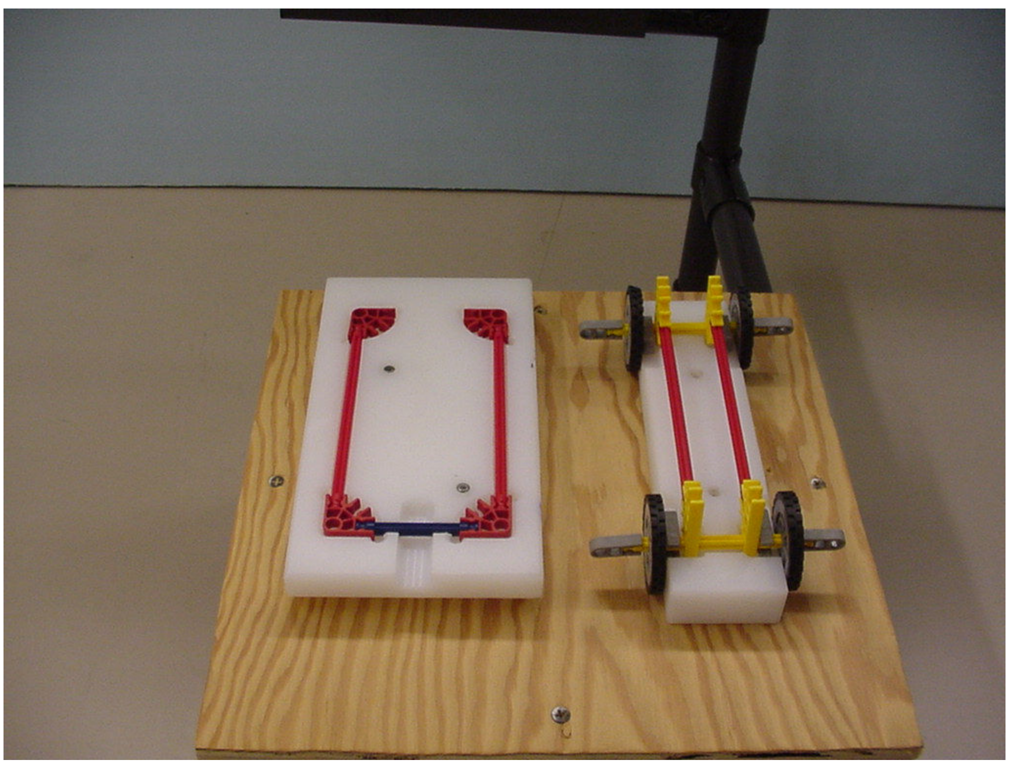

Figure 4D

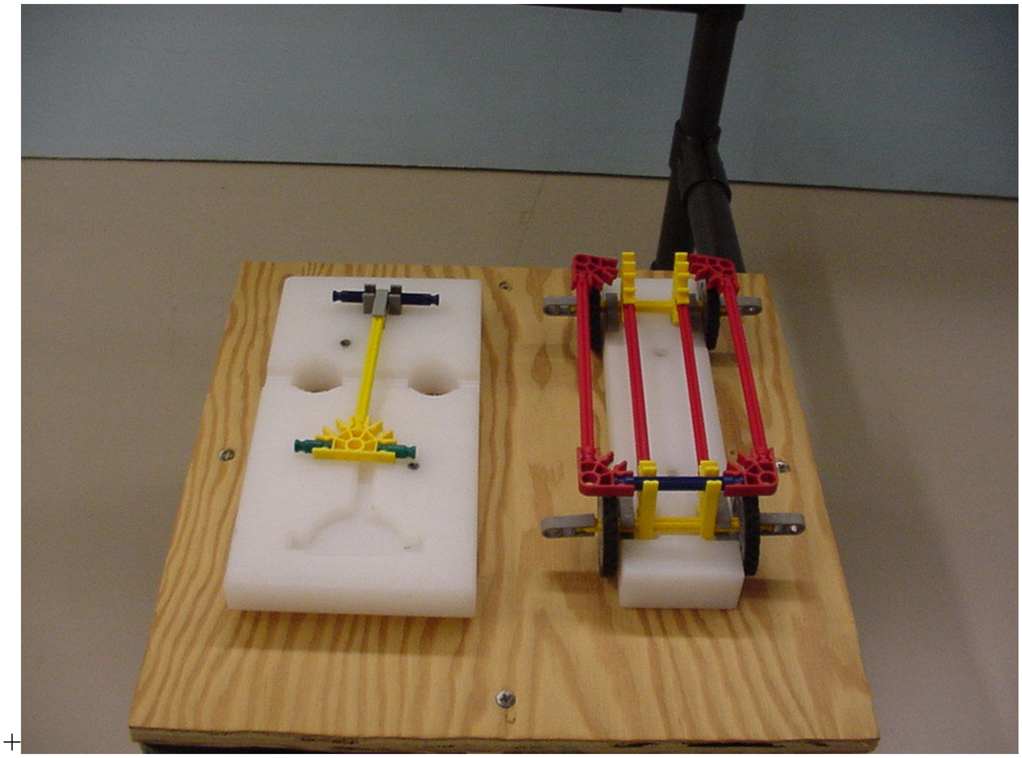

Figure 5D

Appendix E

Summary of Student Survey

All students in all classes are surveyed at the end of class to get feedback on the instructor and the class and content. For this survey the question used was:
"The lab component of this course assisted me in learning the subject"

The choices for student response were Strongly Agree, Agree, Undecided, Disagree , Strongly Disagree, NA
We have been using this new evaluation form for three years and the data from that time covering 173 students showed that 85.5% were Strongly Agree (64.7%) and Agree(20.8%). There were no disagrees just Undecided and Omit.

In addition, the students were free to make comments about the course. The ones below are representative of the comments made by the students on the lab. There were no negative comments.

" The wagon product is an excellent way to show how to use what we learned"

"Liked the hands on work"

" Good lab"

The wagon project was very helpful and informative. We got to incorporate what we learned into what we had to do"

"I like the labs"

"The lab helped understand applications of what happened in the classroom"

"I liked we had hands on experience, rather than just sitting in a classroom going over movies or reading out of a book"

"Fun. It was fun"

"The lab and how the instructor related classroom to the lab"

"I liked how we simulated work cells to get a feel of how they worked"

"Hands on approach"

"The wagon project is an excellent way to show how to use what we learned"

"Very hands on and real world related".

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