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# Design Focused Computer Module for Chemical Engineering Outreach

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# DESIGN FOCUSED COMPUTER MODULE FOR CHEMICAL ENGINEERING OUTREACH

by

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Abstract:

The purpose of this project is to propose the use of a computer simulation to provide middle and high school students with a chemical engineering design experience. Long standing collective efforts between the University of Maine Department of Chemical and Biological Engineering and the Pulp and Paper Foundation have resulted in a variety of outreach programs aimed at students of this age. Recently, both organizations have been increasing efforts in these areas, proposing a senior design project focused on making a portable model demonstrating chemical engineering concepts. This project was examined along with other outreach efforts and teaching modules. The successes and failures of each at addressing chemical engineering outreach became the basis of a new simulation proposal. The program's design was to coexist with the current efforts and become part of a larger picture. The program's function and operation were explained in parallel with these goals. The ability of the proposed computer simulation to address particular failings in current outreach programs and accomplish its own specific goals were addressed.

To My Sister

Contents:

**Introduction**

A year ago I was sitting in Unit Operations, the class that teaches chemical engineers how to operate the large industrial equipment and really defines chemical engineering. A high school student was there as well, shadowing one of my classmates. The entire fifty minute period was spent describing material separation principles using differential equations that even chemical engineering juniors have a hard time comprehending. The class is intimidating enough for engineers, much less a high school student who hasn't had two or three years to adjust to that style of lecture. The actual principles behind unit operations aren't that complicated. Things are heated, moved, processed, and separated. Each one of these steps can be reasonably well-illustrated without bringing math into the picture. The issue is that when you wish to combine these steps into a process the math becomes inescapable.

The idea that chemical engineering concepts can be communicated to younger audiences and the wish to do so is not new. Chemical engineering departments at many universities have middle and high school outreach programs, and the University of Maine is no different. Outreach programs at UMaine include summer camps for high school students, on campus visiting days with demonstrations, and a chemical process computer simulation. Each one of these programs is valuable and conveys a unique idea, and each has its drawbacks as well. In this group of outreach programs, these drawbacks leave a void.This past year the executive director of the Pulp and Paper foundation,Mr.Jack Healy, and the University of Maine Chemical and Biological Engineering Department offered to fund a senior capstone project that would build a physical model the university could use as a portable demonstration unit. The purpose of this thesis is to address this need for a portable and easily deployable hands-on demonstration unit to be used by the University of Maine and the Pulp and Paper Foundation as a tool to teach young people about chemical engineering. The prompt provided to chemical engineering seniors in CHB 479 is shown below in Figure 1:

*The goal is to have a portable device that would allow us to demonstrate a Chemical Engineering concept both in the classroom, and when students come here to visit. Some design constraints are*

- *Is portable – light, with wheels- fits in a trunk*
- *Is safe*
- *Is visual*
- *Is a continuous process*
- *Demonstrates process control or some other concept.*
- *Is interactive – student can make adjustments to change the operation.*
- *Probably utilizes a PC laptop – graphing real time parameters*
- *Looks professional*
- *Could be used by anyone with minimal training.*
- *Can be built for under $5,000.00.*

*Figure1 : Engineering Outreach Module Prompt*[1]

This thesis proposes an alternative solution to the prompt that meets the department's and the foundation's design constraints. It is not meant to compete with or replace the capstone group's project, but to simply provide an alternative solution with different benefits and different weaknesses. This paper will argue that a design-based computer module is a successful way to simulate a unique chemical engineering problem-solving experience.

**Background**

There are a number of existing teaching tools and outreach programs already in use. The success of the proposed solution will be measured against these outreach efforts as well as current computer modules. Its ability to address the issues with each existing program will be the barometer to measure how well it addresses the problem.  In order to create a standard for measurement, this paper will analyze existing outreach efforts and teaching modules, propose a new module to address the shortcomings of its predecessors, and assess the new module's ability to address these shortcomings.

One of the largest outreach programs at the University of Maine is the Consider Engineering summer camp organized by the Pulp and Paper Foundation.  The camp is a three-day long stay at UMaine with the purpose of introducing students between their junior and senior years of high school to all facets of engineering.  In addition to department tours and guest lecturers from all engineering disciplines, the students participate in a series of team-based problem solving activities with the goal of introducing them to the type of challenges they can expect to face as engineering professionals.  The camp offers an in-depth look at many different facets of engineering and uses a variety of educational units to interest multiple learning styles.  The main issue with a summer camp, however, is the scope.  The camp can take a limited number of students, and each year there are many students that apply and are not accepted.  There is a tremendous amount of effort that goes into hosting this camp every year, costing the foundation over $350 per student.

There are efforts within Consider Engineering to simulate the design process. The first of these is the Humpty Dumpty challenge, with gives students a set of materials and asks them to build a device to hold and protect an eggas it travels through the air and lands on the ground.  Students are judged on design concept and project performance. Another project that connects much more with chemical engineering is the water boil. Students are given a set of materials and asked to construct a device to boil a set volume of water as quickly as possible using a tea candle as the heat source. The project is well-designed because it is hands-on for the entire group, makes students work in teams, and is an accurate analog to some chemical engineering problems. The Foundation asks students to rate the effectiveness of the individual programs at Consider Engineering. On a scale of 0 to 4, seminar style speakers rated averaged 2.9, department tours 3.0, and hands on projects and games 3.4[2].

In 2012, the Foundation had 182 students apply for the camp, and 102 were admitted. After the program, 52 matriculated atUMaine, 51 in the college of engineering. A total of 75 students who attended the camp entered a university-level engineering program.[3] The following data were collected by the College of Engineering:

*Table 1 : Student Reasons for Choosing Engineering*

**First Year Student's Participation in Engineering Programs Prior to College Fall 2011 (N=351, n=90)**

| **Name of the Program** | Respondents | % |
|---|---|---|
| **Consider Engineering** | 19 | 21% |
| **High School Tour** | 23 | 26% |
| **GEM - Girls Engineer Maine Tour** | 2 | 2% |
| **VEX Robotics Competition** | 4 | 4% |
| **GK-12 Sensors!** | 1 | 1% |
| **Summer Internship** | 1 | 1% |
| **CAD Camp** | 2 | 2% |
| **Other: lab with sister, SWE, Wind blade challenge, VICA (Mechatronic Competition), Expo, Working with Eng. Professor** | 8 | 9% |
| **Engineering-related program in high school** | 35 | 39% |

Source: First year online student survey

The three largest contributors to engineering attendance were high school programs, high school tours of the department, and Consider Engineering. Almost 40 percent of incoming engineering students said that high school programs were the largest contributing factor to their decision. On-site high school outreach efforts are one of the most effective and at UMaine probably the least explored way to get students excited about engineering.[4]

This year there is a senior capstone group responding to the prompt given by the Chemical Engineering Department. They have designed a reaction that is controlled by a laptop. The entire project fits in a trunk that is approximately 1.5 ft x 1.5 ft x 3 ft. The lid of the trunk opens to reveal a board with "UMaine" spelled out in clear tubing. The project uses the iodine clock reaction, which is a reaction between iodine and starch that suddenly turns dark purpleonce the starch is consumed. The reacting solution flows through the tubing and at a certain point turns from clear to dark. The reaction rate is widely dependent on temperature and concentration, both of which are controlled by the laptop. The end result is that the laptop can control how much of "UMaine" is spelled out in dark lettering. The intention of the unit is be used in conjunction with a department presentation. Someone would first give a talk about chemical engineering and the department atUMaine and afterward interested students could come up and interact with the demonstration. There are some definite advantages to a physical model. It is more hands-on than a virtual model, and surpasses the water boiling project at representing the type of equipment typically used by chemical engineers. Also, there is something extremely gratifying about witnessing a change that you effected in an actual chemical reaction. The system feels more alive and more personal than a simulation. The system provides an actual experience rather than an analog to one.

In industry, chemical engineers push the physical properties of materials and chemicals to their limits. It is not uncommon for material temperatures in a process to be in the hundreds, if not thousands, of degrees Fahrenheit and at pressures exceeding 50 atmospheres. Processescan includemany processing steps and complex control systems. Therefore it is not reasonable or safe to create a scale model of a typical chemical process to take to classrooms. To get around this issue there have been a number of virtual models created to teach students, both at the high school and college levels, about industrial chemical processes.

As a module to accompany a 400-level college engineering class, the University of Michigan Department of Chemical Engineering created an interactive process troubleshooting simulation. The class is titled *Creative Problem Solving*, and draws on examples from multiple engineering disciplines. The simulation accompanies *Strategies for Creative Problem Solving*, a book written by University of Michigan Professor H. Scott Foglerand University of Toledo Professor Steven E. LeBlanc. The simulation begins by congratulating the user on being hired as an engineer for ChemEng Chemicals and announces that your first job will be to figure out why their styrene process isn't operating properly. The module introduces the styrene reaction and the chemical plant, and describes how to interact with the process. A picture of the process and menu screen are shown below:

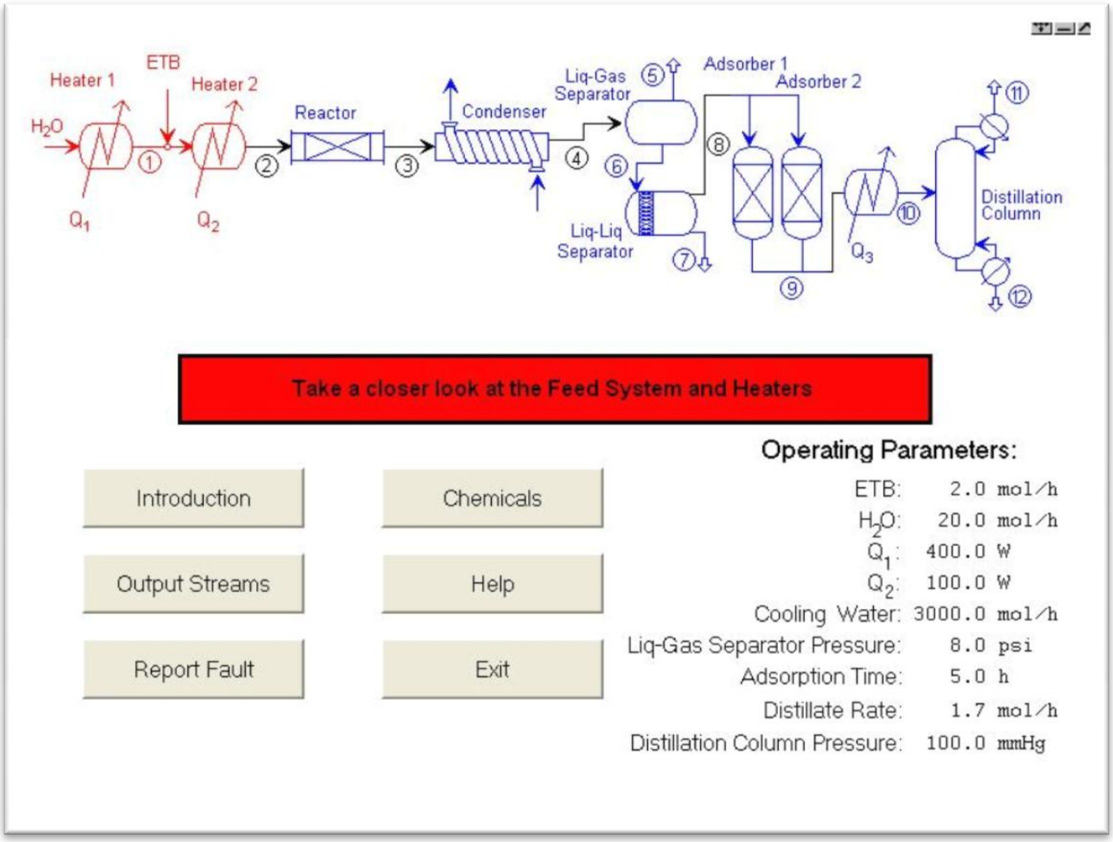


*Figure 2: Sample Screen of Strategies for Creative Problem Solving Module*

Users are told that the properties of the outlet streams are different from normal operation and asked to find the source of the problem. The end goal is to find the solution while spending as little as possible on tests. Users may click on any piece of the process to learn more about its operation and can, for a fee, run tests to check temperatures, pressures, concentrations, and other variables. The model is quite complex, and a basic pre-understanding of chemical engineering equipment almost required. The model succeeds at giving a realistic representation of a typical problem that engineers face in industry, but the complexity of the system can be daunting. For example, there are 28 screens of information before the user can start interacting with the process.[5] The program succeeds in supplying a real life example and a complicated problem solving challenge, but requires a large introduction before the problem can be approached.

Mr. DwaneHutto, project manager at the University of Maine Forest Bioproducts Research Institute, has done a lot of work creating a computer simulation that models achlorine dioxide ($ClO_2$)mill. The simulation is aimed at high school level students and is meant to accompany a presentation. Students are asked to optimize the given process and are required to do some simple engineering calculations in order to do so. The model runs in a program called VisSim that is used to create mathematically rigorous process simulations. A VisSim file viewer is available as a free download on the company's web site. The application is shown below:

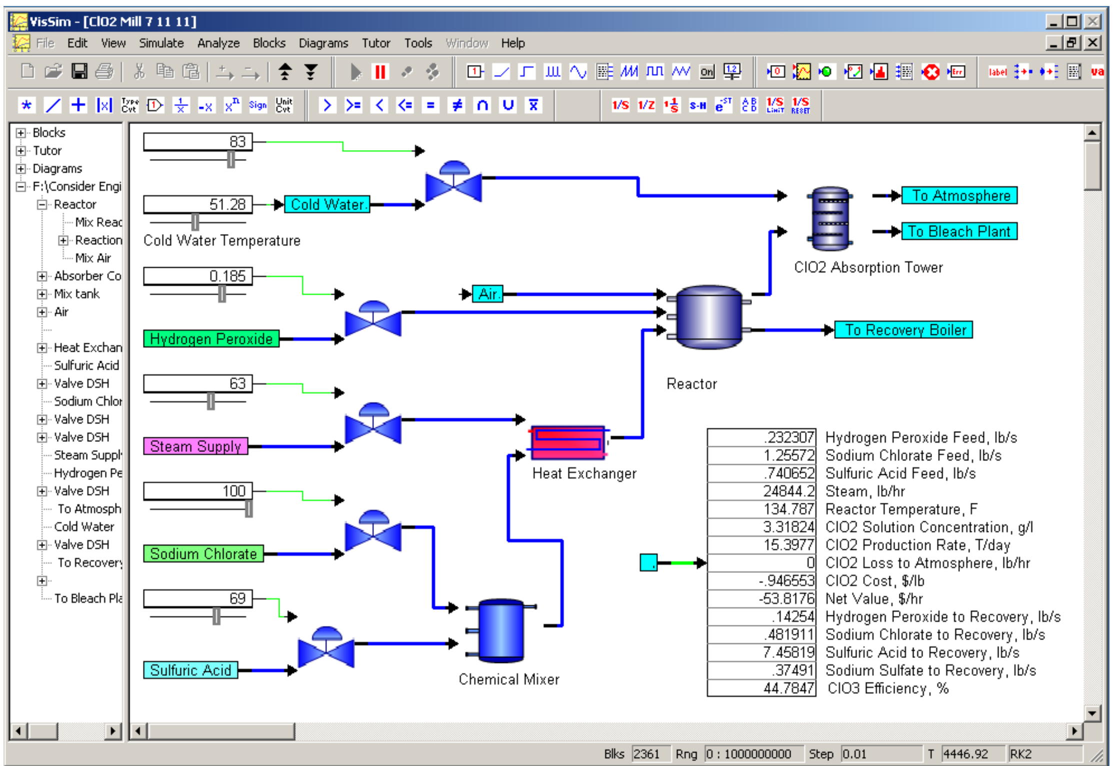


Figure 3: Sample Screen of the $ClO_2$ Mill Optimization Program

The program presents the user with a process schematic, sliders to change input values,and a readout of the process performance. The simulation runs constantly, so that a change in a slider causes and immediate output reaction. During the presentation, students are required to convert mass flow into molar flow, and are taught a simple optimization technique used to find minimum and maximum values given a series of trials. Much like the University of Michigan's module, the program provides a realistic industrial process and typical engineering problem. Since Mr.Hutto can present the program and provide help and feedback throughout the process there is no need for wordy introduction slides.[6]

Each of the current modules and programs for introducing high school students to chemical engineering has advantages and drawbacks. Programs hosted on campus provide the most comprehensive explanation of engineering, but require that students come to visit and are limited in capacity. Exercises like the water boiling project are interactive and are a good introduction to problem solving skills, but do not paint an accurate picture of what chemical engineers do in industry. The portable module designed by the capstone group addresses the portability issue and provides a more realistic picture of a chemical process, but is still limited by its physical size and safety constraints. Computer modules are good at painting a big-picture style problem and realistically representing engineering problems, but each requires downloading andinstalling an external program and requires lengthy introductions or instructor supervision. The programs used by the University of Maine extensively portray the problem-solving aspect of chemical engineering, but the design process receives little to no attention. Three of the staple engineering classes, Unit Operations 1 and 2 and Reactor Design, deal with the design of engineering equipment. Courses such as CHE 478, Analysis, Simulation, and Synthesis of Chemical Processes, and CHB 477, Elements of Chemical Engineering and Bioengineering Design, are two senior classes that deal heavily with process design and optimization. With design being such a focus in the chemical engineering curriculum, it makes sense that efforts should be made to portray the design process to prospective students.

**Proposal**

Formulating a hands-on engineering problem is not an easy task. Engineering concepts build on one another very vertically. Introducing a full-scale industrial process to a high school student is like driving them to the top of Mt.Washington. The view may be pretty but they will never really understand what makes the summit so special until they climb the mountain themselves. The goal then becomes to present the student with a hill, nothing too challenging but enough to give them a taste of the climb. The climb augments our understanding of the summit's beauty; we see our efforts reflected on the slopes of surrounding mountains and recognize the cost paid to enter a sacred place. In order to convey the beauty in a creative engineering solution, you cannot carry someone to the top of the hill. They must experience a taste of the price that must be paid. They must have a part in the solution. The goal of the proposed application is to provide this experience.

In order to facilitate such an experience, the program will be design-oriented. Current computer modules either focus on troubleshooting or optimizing an existing process, or looking at the operation of a single unit. These concepts are certainly a large part of what chemical engineers do, but by no means do they represent the entirety of the profession. The existing programs teach process optimization and troubleshooting in great detail but do not allow students to experience process creation. Modules that look at individual pieces such as reactors, distillation columns, or heat exchangers quickly move past the general concepts and are perhaps better aimed at college students currently taking classes on those operations. Very quickly it becomes necessary to know the math behind these operations in order to optimize them. If it's not necessary to know the math then the exercise degrades into nearly aimlessly changing values until the desired optimization is achieved. For this reason, the pieces of the designed process must interact with each other as to encourage project understanding.

The module will be digital. This choice was made to address portability and scope. A physical model must either be a permanent installation requiring campus visits or must fit in a trunk small enough to be carried in and out of schools. A program can fit on a flash drive or CD and requires no device larger than a laptop. It has no moving parts, requires no maintenance, and always operates the same way. There is no cost to run a computer program and it doesn't break. The electrical components and chemical engineering elements are very intricate and could be easily damaged during travel. Physical demonstrations are limited by the temperatures, pressures, and materials that are safe to bring into a school. Also, if the module is to fit in a trunk then both electricity and chemicals must coexist in that small space. It is possible to keep these two separate but that depends on the physical integrity of the module that could be compromised after bouncing around in the back of a vehicle. Physical demonstrations can only be hands-on for a few students at a time. In Maine, there is a laptop for every student from 7$^{th}$ grade until high school graduation. If a program could be run on one of these computers, each student could have their own module. This makes the programs compatibility with these computers an important design constraint.

**Solution**

The end product is a web based process simulation module. The program is written inJavaScriptand imbedded in HTML. The program can be viewed by any web browser that supports HTML 5, which includes Google Chrome, Firefox, and Safari but not some versions of Internet Explorer. This means that the application could be easily viewed on a high school computer without worrying about whether or not the controls placed on the laptop by the school permit installations without admin permission. The program uses a JavaScript library called Kinetic JS which allows for the easy creation of shapes and pictures. The library is included in the program files rather than remotely accessed over the internet so that if it is ever taken down the program will still work.

The reaction chosen for the module was the Haber cycle. The Haber cycle is a process that reacts $N_2$(nitrogen gas) and $H_2$ (hydrogen gas) over a catalyst to form $NH_3$ (ammonia), a common fertilizer. The reaction is both exothermic and reversible. In the model, some liberties were taken with the process. The math used in each unit operation is similar to the real life equations but none are exact. The reactor equations for CSTR (continuous stirred tank reactor) and PFR (plug flow reactor) follow the proper design equations for a reversible exothermic reaction, only the conversion is dependent upon the reactor volume rather than the catalyst weight as it would in real life. Also, the true Haber cycle uses a condenser to separate ammonia from the unreacted gasses since the boiling points are so different. This model uses a distillation column because it is a more interesting and complicated process step and allows for an incomplete separation of the components. The separation performance is calculated using the Kremser method to determine stage compositions.  Equipment costs are accurate, but chemical values are not.

The module begins by prompting the user with the problem statement.  These windowsare shown below:

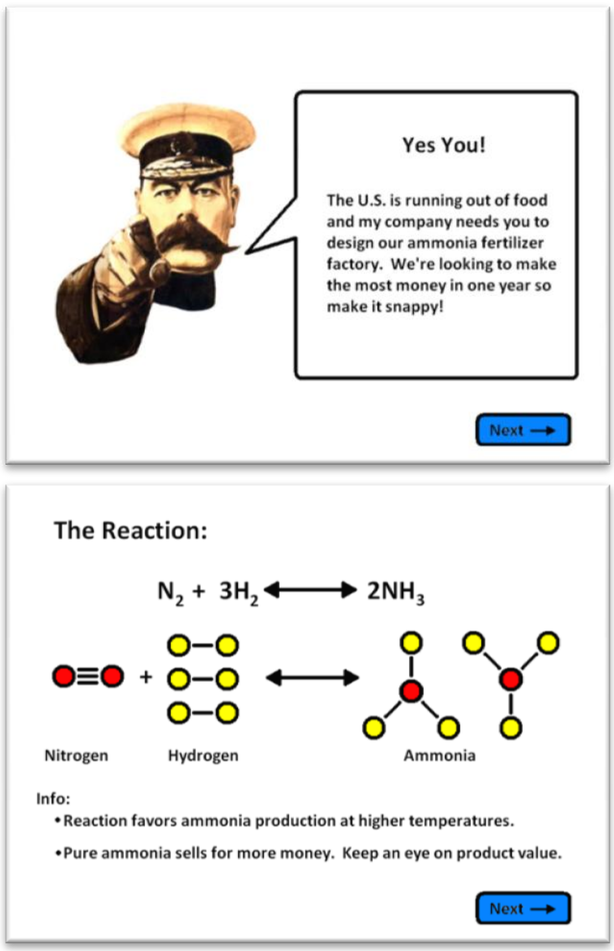


*Figure 4: Problem Prompt Screens*

The window includes the project goal; produce and sell ammonia fertilizer to make the most amount of money after one year.  The simulation presents the general reaction and tells the user that the reaction favors ammonia at high temperatures.  It also mentions that ammonia purity affects how much the product can be sold for.  Upon closing this prompt a second prompt appears explaining simulation mechanics. This window is shown below:

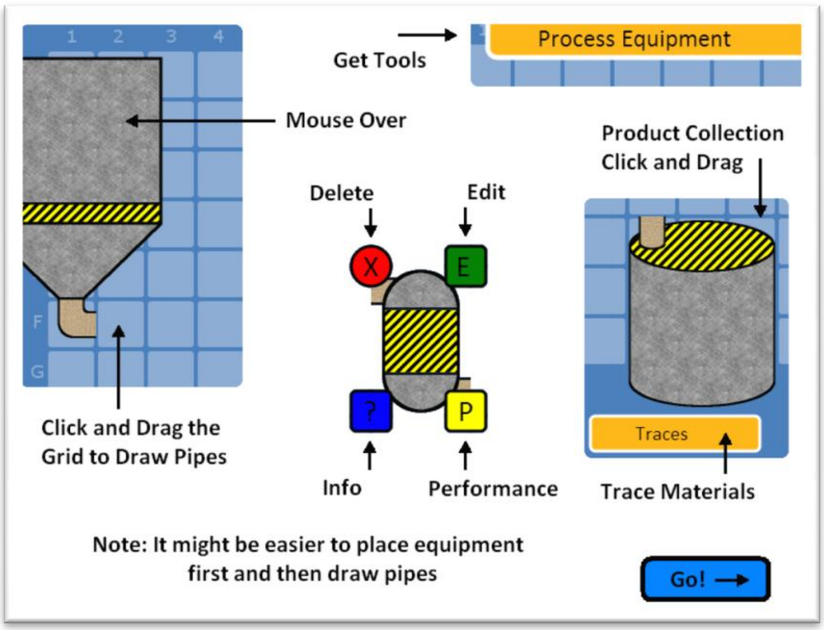


*Figure 5: Program Explanation Screen*

Rather than explaining each piece of equipment beforehand, students are allowed to discover more about each piece throughout the process. The information presented about each piece of equipment is helpful for building and optimizing the process but is not necessary. A trial and error approach could also yield a well optimized solution. The only place where students are asked to do math is at the reactant feed. Nitrogen and hydrogen are reported in mass flows, which means that simply feeding three times the hydrogen, as the reaction equation suggests, will yield a lot of un-reacted hydrogen. The math for converting mass flow to mole flow is explained in the help file for reactant feed.

Once the short introductory screens have been viewed, the user may interact with the program. When the mouse is moved over the menu bar the figure slides down to present the various pieces of equipment available to the user. Placing the mouse over one of these pieces changes the shape of the pointer to insinuate that the object is clickable. Clicking the piece places it in the grid where the user can drag it wherever he or she may choose. The first few processes assembled may not even produce ammonia at all. Students are not expected to know how each piece operates and may need to examine the help files in order to recognize that a reactor is used to alter materials and the column is used to separate them. Each piece of equipment has four functions associated with it. The first is that it can be removed by clicking on the x button. Second, the piece may be altered by clicking on the E or edit button. This allows the user to change the items size or utility. The third is the P or performance button, which provides feedback on the equipments operation. Clicking on this button pulls up a screen that reads the inlet and outlet properties, certain internal variables such as conversion or a chart of tray concentrations, and the overall equipment cost. Lastly there is a "?" or info button that provides a screen informing the user about what the piece is and how it operates. Any piece may be removed allowing for alterations, and there is no limit to the number of pieces a student may use.

In order to see how the process pieces could be used to reach a creative solution, we will first look at how those pieces operate. Figure 6 below shows the primary pieces of process equipment.

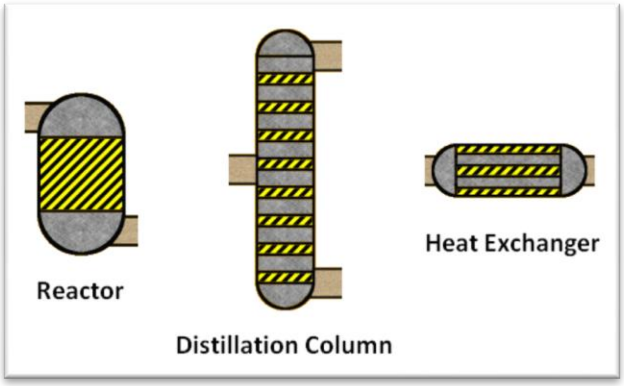


*Figure 6: Process Equipment*

The first piece of interest is the heat exchanger. In this application, the heat exchanger's only function is to heat the stream. The reaction will not take place if the temperature in the reactor is less than 250°F. The feed temperature is 70°F so it is absolutely necessary to use a heat exchanger at some point in the process. The performance or ability of the heat exchanger is dependent upon the exchanger's area and steam flow utility. Increasing either of these values makes materials leaving the exchanger hotter.These principles are described to the user in the exchanger's help file.The next piece is the reactor. The reactor converts nitrogen and hydrogen into ammonia. If the stream leaving the reactor is hotter than 600°F, the reactor will explode. Since the reaction is exothermic, or produces heat, it may be necessary to cool the reactor using the coolant utility to prevent explosion. The primary variable controlling the reactor's operation is its volume. Increasing the volume will increase the nitrogen conversion, which is the proportion of nitrogen that reacts to form ammonia.

Next is the distillation column. The distillation column is used to separate ammonia from un-reacted nitrogen and hydrogen left behind by the reactor. Operating the column is similar to boiling sea water; the salt stays in the boiling water while the water vapor can be condensed and is safe to drink. The problem is that not all chemicals operate in this way. Usually, boiling a solution only concentrates one of the chemicals. A distillation column basically boils these chemical multiple times so that the “light” chemical comes out the top and the “heavy” chemical leaves through the bottom. The number of stages or trays in the column is equivalent to how many times the boiling process occurs. This isn’t really how the physics is taking place but it’s a decent analog. The column in this program has three parameters. First, increasing the number of trays makes chemicals coming off the top and bottom more pure. Next, is the feed tray may be moved up or down. Changing the feed tray alters how many concentrating steps the “light” and “heavy” chemicals go through, altering the separation. In essence, the further the feed tray is from the top or bottom, the more pure that stream will be. The third is column diameter, which increases tray efficiency allowing each stage to separate chemicals better. Again, this does not follow the physics perfectly. The important thing to take away from the column is that it is a separation step.The more trays and the larger the diameter, the more pure the top and bottom streams become.Since the nitrogen and hydrogen leaving the top must go somewhere, there is a trash can included to send these materials to waste management.

Nitrogen and hydrogen are fed to the system from the hopper, which appears on the left side of the screen (visible in Figure5). The ideal ratio is to feed one pound of hydrogen to five pounds of nitrogen. This is explained to the user in the hopper’s help file. The end goal of the system is to make the most amount of money after one year. That being said, everything in the simulation except pipe costs money. There is a charge per pound for nitrogen and hydrogen. Steam for the heat exchanger and coolant for the reactor also cost money. The larger a piece of equipment is, the more it will cost. The more pure the ammonia, the more it can be sold for. The total money made from selling ammonia is the income, which is subject to a 35% tax rate. Once a process is complete, meaning that there are no unconnected pipes, the simulation can be run. Running the simulation exposes a report card detailing the system's economics. The first time around, the system will probably not be very profitable. This is where the tuning comes in. The user may go back to each of his or her pieces and change any parameter they like. They can view how each piece performed on the previous run to help decide if a reactor needs to be larger or if a column needs more trays.

The one piece not mentioned above that is perhaps the most important is the T-shaped pipe. The T-pipe is a crucial piece because it allows for the merging of streams. If the separator is used, the T-pipe opens up a large variety of process designs. Without a way to combine streams, the design process becomes connecting piece 1 to 2 to 3 to 4. Since the T-pipe breaks the process' inherent linearity, it is potentially a large source of process diversity. Piece 7 can now lead back to piece 3 and so on. The ability recombine streams allows for a creative use for the waste stream of un-reacted nitrogen and hydrogen. Multiple separations can be used to feed back more nitrogen and hydrogen increasing ammonia production and process profitability. Through a creative use of heating, reacting, separating, and mixing the user can build and test a variety of process designs.

**Example**

The open-endedness of the module creates a system where many different solutions can produce high net profits.  Some students may approach the problem by using many operation steps while others might choose a simple process and spend more effort getting equipment sizes just right.Two sample screens for comparison are shown below:

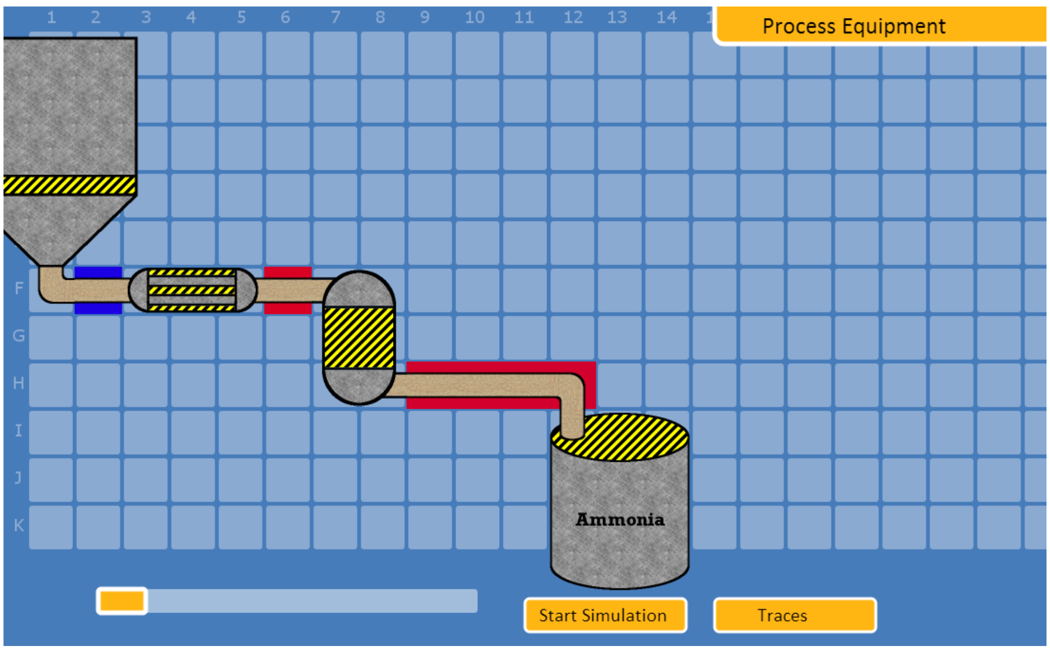


*Figure 7: Sample of Completed Project A*

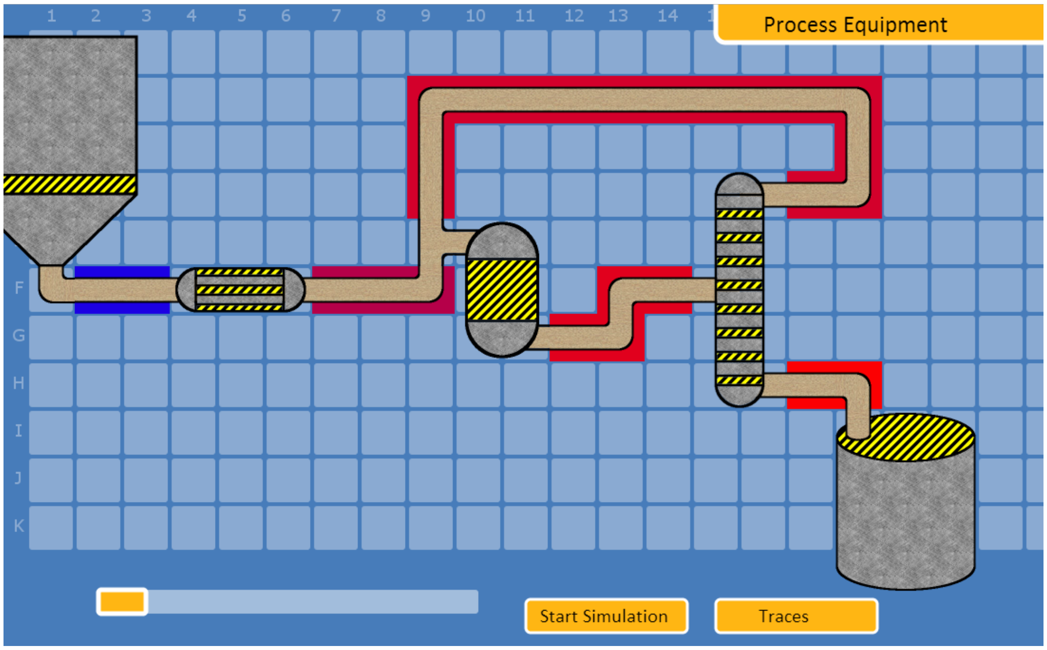


*Figure 8: Sample of Completed Project B*

First let's look at process A. This student predicts that a simple process will be less expensive and has gone with the bare minimum. From left to right, their process contains a heat exchanger and a reactor. To get this system to be profitable, it is necessary to change the feed flows of nitrogen and hydrogen to the 5 to 1 ratio mentioned before, increase the heating capability of the reactor by raising the steam flow rate or increasing exchanger area, and changing reactor size to consume more of the reactants. Since they have few pieces worry about, they can focus on making small changes in exchanger and reactor size to gradually increase net profit.Eventually, this system results in around five million dollars profit after one year.

Student B believes that a more complex system will yield better results. He or she is clever, and realizes that un-reacted nitrogen and hydrogen can be separated using the column, seen far right, and then fed back into the reactor using the T-pipe. It will be harder for this student to balance the sizes of all the equipment. The more pieces in a process, the more those pieces begin to act on one another. Changing one piece could throw something off down the line. Even with the basic recycle scenario student A has created, he or she may have to jump between tuning the reactor and distillation column a few times before the system begins to settle on a maximum net profit. In the end, student A will be probably be able to get closer to six million dollars after one year. Perhaps he or she will try adding more reactors and distillation columns to see if they can increase the profits to seven million dollars. In this way, interaction with the simulation breaks down into a cycle of building, testing, changing, retesting and rebuilding.

The program intentionally provides no examples so that the simulation is truly a blank slate. There are some hints that talk about temperature and product purity to give some guidance but in the end the process design must come from the user. The purpose of the module isn't to teach the user how chemical engineering equipment works. If students forget everything about reactors and distillation columns the module is still a success if they remember what the design experience felt like. Since people will interact with the simulation in their own way, the design experience will be different for everyone.

The color of the pipes in Figures 7 and 8 represent the temperature of the materials within. This can be changed to represent the concentration of individual chemical components. The module is similar to the University of Michigan's in that you can examine each of the pieces, but provides more exploration tools. Each piece of equipment offers its own set of editable size and operation parameters, performance readouts that let the user know what's flowing in and out, values of internal variables, and the equipment's cost, and an information window describing the principles behind the unit's operation.The module is more visual than the others, although there is still no animation. Animations were excluded primarily because the simulation only analyzes one grid square at a time. If it were also to show fluid flowing through the pipes fluid would flow out the bottom of the column, out the top, around the recycle loop, and then back out the bottom. This would look confusing and wouldn't accurately represent how these systems work.

**Analysis**

As a computer module the program meets many of its targets, and fails at others. Returning to the goals laid out by the Chemical Engineering Department, the program more than satisfies the portability requirements. It runs on nearly any computer without installation and can be accessed either from a CD or remotely over the web. It is safe, and it demonstrates the application of chemical engineering principles. It is interactive, and doesn't require extensive training to operate or introduce. It is not, however, set up as a continuous process and the visuals may be a little too cartoon-like to keep high school aged kids interested, although this may open the door to a wider age group.

In order to assess program design we will first look at the process feedback methods. The program does not run steady state. The primary reason is that the ability to change one slider and watch a value instantaneously change separates the user from the physical change they are making. The optimization process begins to mimic rapid prototyping where the user can make many changes very easily and instantly see the end effect of each of those changes. This can have the effect of turning the simulation into a game of changing sliders and watching values, without any thought about the way that the process is operating.  Removing the steady state atmosphere makes the rapid prototyping process much less practical.  Users are forced to pick a value and then take the time to run the simulation, and then are allowed to view the results of this change. This is an attempt to create a time investment, so that it becomes easier and quicker for the user to think consciously about the decisions that they are making, rather than flail around wildly on sliders.  It does not guarantee that the user will think about what they are doing, but it does encourage it.  Mr.Hutto's program runs steady state but avoids this issue in some ways since it is meant to accompany a presentation. Mr.Hutto can, to some degree, control how students are interacting with the module.  Another point about rapid prototyping is that in many ways chemical engineers are forced to operate in that way. Chemical engineers complete a pump optimization lab in their junior year.  The lab reduces to turning a knob and measuring the resulting pressure.  If the students' understanding of how the pump operated was not directly assessed as part of the grade, the lab reduces to turning a knob until a max value is achieved.  In industry, this may be the extent of the work required.

Another aspect of not operatingcontinuously is that the time requirement for running a simulation encourages students to change multiple parameters before running the program.  This means that it may be difficult for students to pinpoint the affect that any one of those changes had on the process and the final value.  While this ambiguity may make using the program a little harder, it could be a blessing in disguise.  Not having a clear cause and effect encourages the user to think more about how the variables are interacting, and the program does provide tools to facilitate this.  Students can look at the performance of each piece of equipment which helps to connect reactor volume to nitrogen conversion and column feed tray to separation performance. The driving force for this style of operation really gets back to the original goal of the project. The program does nearly all the math for the user, but leaves the design choices almost completely up to the student.

The means for placing pipes is probably the largest failing of the modules operation. Connectors are hard to use in most process design applications. The design software used by chemical engineering seniors called Aspen uses a method where the user clicks on the outlet of one piece of equipment and then on the inlet of another. The software then automatically draws a connector. The disadvantage to this is that it can be difficult to get the connector exactly where you want it. The program draws the connector over another piece of equipment or using more angles than necessary. You can drag the connector, but often times it looks even messier than before. For this reason a connecting method where pipes follow the user'smouse was chosen. This has the advantage of allowing users to place pipes wherever they want, but also makes the mechanics behind this process messy. The program works by always drawing a straight pipe first. This is confusing when users place pipes at outlets because the pipe must go forward first rather than up or down. Also, people have the tendency to draw pipes in straight sections. The want to draw a section flowing to the right, then click again and begin drawing pipes up. The system can't draw an angle first so the pipes do not appear to be connected.

There are many advantages inherent in using a program over a physical model, and even more to one that can stand alone without additional explanation. The primary advantage to this application is distribution.For example, CD's containing the program could be handed out at engineering fairs or department tours. Since the application provides a certain amount of instruction and can run on almost any computer, the program could be viewed at home and doesn't need to take time away from the department's presentation. The program uses chemicals, temperatures, and pressures that would not be reasonable for a teaching module, especially a portable one. The ease at which users can create process equipment and alter its size would be difficult to replicate in a physical model. As a computer application, the complexity in terms of process steps and required instruction is simpler than the Hutto and University of Michigan models. It takes steps to encourage an understanding of how the pieces of the user's process interact with one another and discourages rapid changes in process values during optimization. The application is unique in that it allows students to design their own process. The invention process creates an increased emotional investment in a project:

*"Weinstein (1980) … argues that two conditions must be fulfilled for an optimistic bias to arise: (a) the event is perceived as controllable and (b) people have some degree of commitment oremotional investment in the outcome. Both conditions are likely to occur for inventors"*(Åstebro, Jeffrey, and Adomdza255)

The proposed module creates an emotional investment by giving students control of the design process. They are creating something entirely new, rather than just returning a process to its natural state. Each student's process is unique and they have ownership over its performance. They are completely responsible for its results. Investment and responsibility are why students at Consider Engineering ranked the hands on projects the best. They were asked to create something new and allowed to take pride in their work. The proposed computer module attempts to recreate this.

When West Point wanted to create a bridge design project they chose digital. Their reasons were as follows:

*"National technological literacy standards characterize the design process as systematic, iterative, creative, based on criteria and constraints, and purposeful (meaning that the process culminates with a functioning product or system). The typical model bridge-building project fails to meet this standard."* (Ressler, Ressler 3)

They observed that in typical physical bridge building designs were not derived from "systematic processes" but rather from existing bridge designs. In other words, the experience was more like an art project than an exercise in engineering problem solving strategies. Students were afraid to try more creative designs that would fail embarrassingly during testing. An example of West Point's end result is shown below[8]:

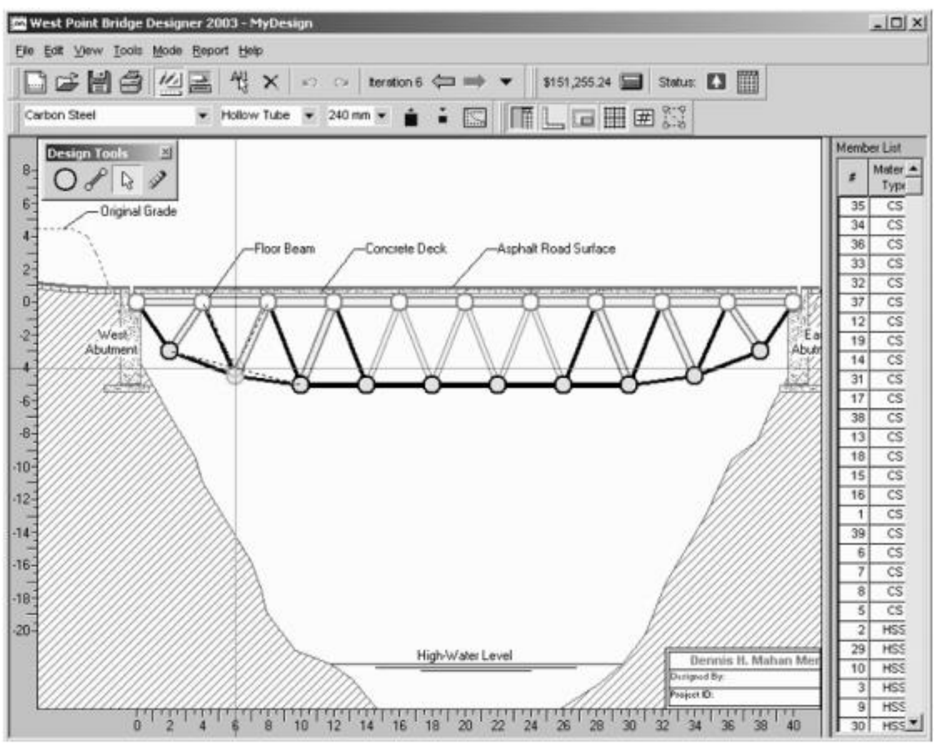


*Figure 9: Sample of Completed Bridge Design*[8]

The computer application proposed in this paper meets the criteria proposed by West Point. It is creative because students must work individually or in teams to create an original solution, iterative because changes and adjustments to the process are almost guaranteed a necessity, and purposeful because it connects an engineering project to feeding America. While the program architecture does not guarantee that the user must understand chemical engineering concepts, the delayed response to change makes in the least a systematic approach necessary. The module is bound by some of the limitations of a computer program, but succeeds within this framework.

**Conclusion**

The goal of the computer application was to create a unique problem-solving experience within a chemical engineering context. There are many challenges that make providing such an experience difficult. The complexity of chemical engineering processes makes them hard to explain without long presentations or introductions. The modeling software currently available for creating simulations is meant to be mathematically rigorous rather than visual or user friendly, and drawing connectors in any type of process simulator is difficult. Providing a chemical engineering design experience is important but challenging to do withboth physical and digital models. The proposed application attempts to address these issues, and is more successful in some places than in others. In the grand scheme of things, the program is a piece of the much larger puzzle. There are advantages and disadvantages to each of the examined solutions. The proposed module shares many of these successes and failures but none are exactly the same. In this way the proposed program has a unique and important place in the big picture, and successfully fills its role in the overall goal of chemical engineering outreach.

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## Author's Biography

Marc Beauchemin was born in Portland, Maine on October 2, 1990. He grew up in Lyman and Saco, Maine, and graduated from Thornton Academy in 2009. At the University of Maine, Marc majored in Chemical Engineering. He is a member of Tau Beta Pi and a recipient of the Pulp and Paper Foundation Scholarship.

Upon graduation, Marc plans to begin working for Metso Automation operating in North America and Europe.