AC 2009-2320: ALIGNING ASSESSMENT TOOLS WITH COURSE SUBJECT AND GOALS

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This presentation outlines our experiences aligning assessment tools developed outside of your academic department with the goals and structure of your course. We have restructured two very different assessment tools for use in a junior level Chemical Engineering Fluid Mechanics and Heat Transfer course. The first is a critical thinking rubric developed by the Center for Teaching and Learning (CTL) on the author's campus and the second is the Thermal and Transport Science Concept Inventory. At issue are how to fit in new and different assignments, how or if to give students credit for these activities, and how to adapt the instruments to your course and material.

Introduction

In assessing a novel pedagogical approach, referred to as CHAPL, developed at Washington State University (WSU) which combines several effective pedagogies in a single course including: the forming of Home Teams for conducting projects and solving homework problems (Cooperative Learning - **CL**); manipulating fluid and heat exchanger equipment to observe principles in action (Hands-on Learning - **HL**); conducting brief small group exercises to perform derivations and discuss implications (Active Learning - **AL**); and assigning design problems to stimulate procurement of knowledge about general principles (Problem-based Learning – **PL**), we have adapted two existing tools for assessing things other than basic course knowledge for our use. Namely a critical thinking rubric developed for papers and presentations in the humanities and social sciences, and the Thermal and Transport Sciences Concept inventory, which is much broader than what we needed.

This paper will begin with some background information on how and where CHAPL is implemented and a brief description of the equipment used. This is followed by a chronological description of the adaptation process used for each of the assessment tools. Details of the current implementation and sample results follow, along with a discussion of the lessons learned during the adaptation process.

Background

The CHAPL pedagogy was developed in a required junior level Chemical Engineering course, Fluid Mechanics and Heat Transfer. This course is two credits and is offered only in the spring, as it has another junior level course, Introduction to Transport Processes, as a prerequisite. In recent years the class size has varied from 15 – 30. The class meets in two one-hour sessions each week.

Figure 1. Typical CHAPL Classroom

The approach has undergone steady refinement so that we are now receiving positive feedback from the majority of the students involved. In this paradigm students work in highly interactive groups to solve problems cooperatively and propose designs as they test concepts using hands-on modules. Fig. 1 shows a typical CHAPL session. There is little lecture; instead the instructor and teaching assistants (TAs) act as preceptors, correct misconceptions and, when necessary, help resolve group conflicts. When student groups are stuck on what to do next or on a particular concept we ask "Let's hear a sample discussion among your group of what you are thinking so far" – often, with a tip thrown in here and there, the students work out the solution themselves. Other times we will direct the students to a particular section, paragraph, figure, equation, etc. in a text book that succinctly deals with the issue at hand – we'll say, "Someone read this, and then see how that impacts your discussion."

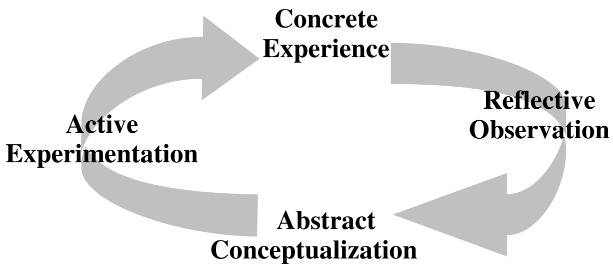

Figure 2. The Kolb Learning Cycle

Our goal in this is to guide groups through Kolb's experiential learning cycle (Kolb 1984, Kolb 1986), shown in Fig. 2. This entails: Concrete Experience (CE) or a look at what is happening here and now as module process variables are manipulated, Reflective Observation (RO) or what is the meaning of what was just observed, Abstract Conceptualization (AC) or how can these observations be quantified mathematically, and Active Experimentation (AE) or how can process variables be adjusted, mathematical formulas reduced and new information added to complete understanding of important concepts.

One of the pedagogical tools central to our approach is the "Jigsaw" or "Expert" group member concept advanced by Aronson *et al (1978)*. Students are split into Home Teams and each team member is assigned one of the concepts relevant to the broad field of fluid mechanics. New Jigsaw groups are formed and comprised of the students from each Home Team who are assigned the same concept. Each group is provided access to a hands-on module which is set up to allow exploration of their concept. The Jigsaw groups are charged with the task of studying their concept and developing a Kolb Cycle learning exercise involving all four CHAPL components. These exercises will then be used when they return to their Home Team. After two sessions, the Jigsaw group members return to their home teams and take turns guiding the rest of their team members through the exercises they developed. The students then have a homework problem written to correspond to the hands-on module. These problems are not trivial, and frequently require iterative solutions. This promotes individual accountability, as each team member owns a critical piece of the cumulative information puzzle needed to solve assigned problems. The entire process is repeated for the heat transfer portion of the class.

The hands-on modules are designed to allow groups to examine the basic principles behind pressure losses, flow regimes, flow measurement, the application of the mechanical energy balance, thermal energy balances, and the determination of heat transfer coefficients and heat losses. There are currently eight different modules, as described in Table 1.

Table 1. Hands-On Modules

- Reynolds No. – dye/flow through clear pipe
- Pressure drop through fittings & valves
- Flowmeters – venturi, & orifice
- Extended surface heat. ex. – radiator/fan
- Kettle boiler/steam condenser
- 1-2 Shell and tube heat exchangers
- Fluidized bed – compressed air thru sand
- Double pipe heat exchangers

This should provide students with an environment where they can practice and develop essential non-technical skills such as teamworking, oral and written communication, and critical thinking. The pedagogy should also lead students to a deeper conceptual understanding of the material. The author's identified a pair of assessment tools aimed at measuring student achievement in two of these areas, critical thinking and conceptual understanding, and adapted them for use in the course.

Adaptation

Critical Thinking Rubric

The authors identified a rubric, developed by the CTL, for rating a student's thinking in a presentation or writing assignment, see Appendix 1. Much of this rubric is clearly not applicable to the types of presentations we normally see in a chemical engineering course. To adapt it we followed a fairly simple algorithm: Identify appropriate factors from the existing tool, Synthesize an appropriate construct that these describe, Develop appropriate scoring examples, Test the resulting rubric, Revise the rubric.

Portions of the CTL rubric describe a common problem solving method. Identify the problem, make assumptions, pursue a solution methodology and evaluate your solution. Taking these four categories leaves us with a rubric that can measure critical thinking in the context of problem solving. A pair of graduate students came up with examples of what might be typical for each score in for a chemical engineering problem. This rubric, see Appendix 2, was then used to rate group presentations on the design project the students did, and later brief individual papers. The brief papers were one to two pages on the following question:

> Imagine you are planning on adding a swimming pool and hot-tub to your home, and being an Engineer, you see no reason not to design it yourself. Consider the water handling system for this. What pieces of equipment would need to be included? What do you need to think about when sizing the pump? Why?

The following scoring methodology is used. First each individual participating in the rating process reads and scores a paper. Then raters then come together to discuss the ratings and why we chose the scores we did in order to come to consensus on the meaning of the scores. For a baseline we defined a score of four as what we would expect from a graduate who was well prepared and ready to work, i.e. professionally competent. As long as raters did not score a paper more than one point different from each other, or cross the competency line their scores were 'in agreement'. After the initial paper to establish consensus, the papers were divided amongst the raters. Each paper is rated by at least two people and we periodically repeat the initial rating process to ensure that we are remaining in agreement. The raters in this case were interested faculty and graduate students.

After a few uses we began to notice that some of the disparity in our ratings came from the breadth of topics compressed into each area. For example, one of us might rate a paper low on assumptions because the student left out some significant heat transfer considerations, while another of us might have rated the same paper highly for the student's assumptions regarding physical size and location. After much consideration and discussion we developed the current rubric, see Appendix 3.

In this version we have separated out the various types of assumptions as well as restating that rather than looking for the students solution method, we are interested in their understanding of the relationships between the principal concepts of the subject, the equations they might have chosen to use, and their design. Again this is broken out by subject. We have also added a section to rate the students' thoughts on how and why they specified their equipment, and a section rating whether they have put in sufficient thought that they can clearly communicate their design. These changes shift the rubric from critical thinking in chemical engineering problem solving, to critical thinking in chemical engineering design.

Concept Inventory

One of our hypotheses has been that by teaching in this manner, the students will gain an enhanced and longer lasting understanding of the concepts. To help measure this, we chose to use selected questions from the Thermal and Transport Sciences Concept Inventory (Streveler, et al 2008). Again our algorithm was to identify the parts of the existing assessment too that were applicable, then to utilize the modified tool, and to revise the tool based on the experience in its use. The initial sorting was done by a graduate student on the project. He tried to select questions that had to do with the course content. He then divided the questions into three sets, to be given at the beginning, midpoint and end of the semester. The first set contained a mix of fluid mechanics and heat transfer concepts, the second just fluid mechanics, and the final just heat transfer, in order to match the course content. The questions were divided so that each concept was covered by two of the tests as appropriate. This has worked fairly well, aside from a slight oversight that left one heat transfer concept only covered in the final set.

We began to see issues when we wished to expand use of the inventory to determine the impact of a single class session on conceptual understanding. This required a new set of questions more specifically developed for the subject matter of that particular class session. The question set developed for this ended up broader in that it included questions that were aimed at knowledge gained and not just conceptual understanding.

When we realized this, we began developing a database of all the questions we had available, including some that were part of the course exams. This led to a two things, first a discovery that the graduate student who had done the initial sort of questions from the Thermal and Transport Sciences Concept Inventory had missed some questions due to their being phrased in different ways than the course content used. For example, we do not discuss friction losses in terms of momentum flux. Secondly we discovered that we were not working from a common understanding of what was meant by 'concept'. After some discussion we decided that a conceptual question was one that was aimed at examining a students learning primarily in the second and third levels of Bloom's taxonomy. This then led to another discussion wherein we reminded ourselves that taxonomies such as Bloom's classify knowledge but do not place value on the different types.

Current Implementation and Results

Critical Thinking Rubric

Currently the students are given the following problem statement:

> You need to design a system to transfer and cool hot, 98% Sulfuric acid from a mixing facility at your plant, at ground level, to a system on the third floor of one of the buildings. Consider the flow and heat transfer systems for this.
>
> a) What do you need to think about when designing the system? Why?
> b) What pieces of equipment would need to be included? Why?
>
> Your design reflection will be assessed using the attached *Guide to Rating Critical Thinking* and you'll receive 2 points for each section if you have a 1.5 average on all sections. For the mid-semester reflection you need a 3.0 average and for the end of the semester reflection a 3.5 average. One point bonus per section each time your average is 0.5 above these levels.

This gives the students some credit for the assignment and provides an incentive to take it seriously without causing too much change to the grading scheme for the course. An issue we have had with this is that we would prefer to do all of the scoring at one time at the end of the course to avoid any time related fluctuations in scoring. For example, if I am in a bad mood due to having received my retirement statement the day before, I may score more harshly than I otherwise would. Unfortunately, students need feedback so we are currently attempting having the professor score the papers prior to the semesters end for the purposes of student feedback and grading.

The current rubric allows us to come to a consensus on a students score much more quickly than the previous version, as we no longer have to hash through how we have mentally weighted different aspects of one of the rubric categories. On the downside it has expanded from four criterion to nine, and so takes a bit longer to rate a paper than with the previous rubric. Another issue we have run across has to do with the range of the scores. Since we have established professional competency at four, we do not expect to see our students score above a four, especially since we are dealing with Juniors. A side-effect of this is that our scores tend to cluster in the two to three range. We can compensate somewhat by allowing half scores, i.e. 2.5 or 3.5, we are looking at a very narrow range of results. The other thing that sometimes develops when bringing in a new rater has to do with the meaning of the scores. There is a slight tendency towards shifting away from the standard of professional competency towards more of a grading mentality. Such as: 'well this is the best paper out of the lot, so it must be a six (or maybe four if the rater is thinking about the competency line.)' This is why the periodic check-in repeat of the initial consensus building is important.

As can be seen in table 2 below, the reliabilities have been fairly consistent, with some qualifications. In 2006, an education expert assisted with the ratings; however his scores were consistently higher than those of the other raters. When we threw out his scores we attained a very high level of agreement, as 70% is usually considered sufficient. Similarly in 2007, with one of the sets of papers, a new individual to the project rated with the grading mentality mentioned in the previous paragraph. Again neglecting these outlying scores results in excellent agreement. A post-hoc adjustment, i.e. Z-scores, can allow us to utilize the differing scores.

Table 2: Summary of Inter-Rater Reliability

Year	2006	2006 w/o non-engineer	2007 set A	2007 set B	2007 set B w/o non-conf. rater	2008
Inter-Rater Reliability	25.00%	90.00%	92.00%	57.00%	100.00%	82.46%

Figure 3, below, shows the results of the critical thinking rubric use in the spring 2008 offering of the course. As can clearly be seen, there is not a visually compelling difference on any of the scores. This may be at least partially due to the compressed range discussed earlier.

Figure 3: 2008 Critical Thinking Rubric Results

Concept Inventory

The concept inventory is also given at three points in the semester, as previously described. Again the students are given a small amount of credit for turning in the assignment. Figure 4 below shows some typical results. As might be expected the students grew in conceptual understanding over the course of the semester.

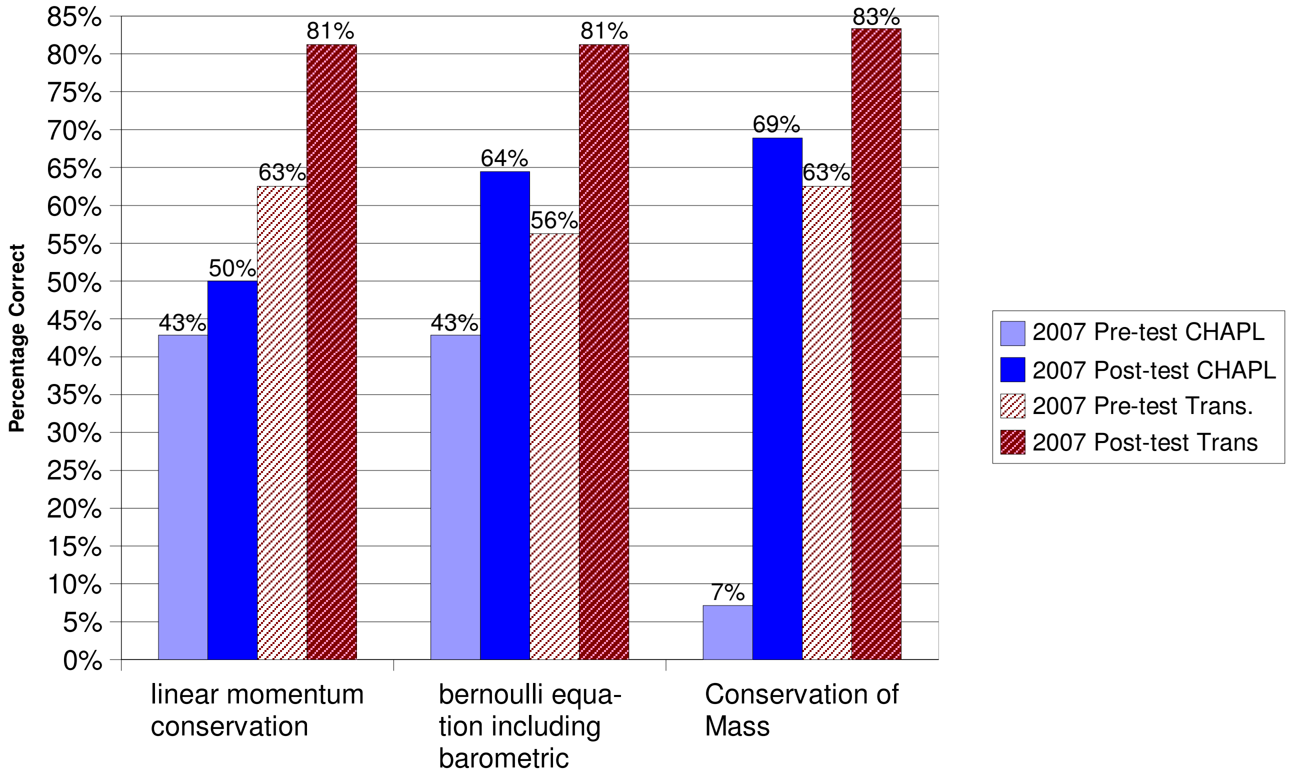

Figure 4: 2007 Concept Inventory Results for Fluid Mechanics Concepts, these results compare a section that was taught in the CHAPL pedagogy for the full semester to one that transitioned from lecture to CHAPL over the course of the semester.

Conclusions and Lessons Learned

One of the primary lessons we have gained from this experience is that developing an assessment tool takes time, use, and significant discussion. Problems with the initial version of the critical thinking rubric were not noticed during the very first, and limited, use, but rather showed up the following year in the first use involving individual assignments. This was the first instance in which there was sufficient number of uses to develop a feel for how the instrument was working and where it needed improvements. There were few problems with the concept inventory because it had been rigorously developed and reviewed prior to our use of it, however our initial implementation would have benefited from more review and discussion. Similarly the development of new questions was aided by our taking the time to discuss and build a common understanding of what the questions were meant to probe. An interesting side note that we have seen from this is that, although the input of experts in the field of education is extremely valuable in guiding our discussions and methodologies, the work itself has to be done primarily by engineering educators. This is perhaps seen most clearly in the critical thinking rubric where in 2006 the ratings of the education expert had to be neglected because he was rating based on a different expectation of student performance.

Acknowledgments

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Appendix 1 – Initial Rubric from CTL

Guide to Rating Critical Thinking

Washington State University

2004

1) Identifies and summarizes the **problem/question at issue** (and/or the source's position).

Emerging ***Developing*** ***Mastering***

Does not identify and summarize the problem, is confused or identifies a different and inappropriate problem. Does not identify or is confused by the issue, or represents the issue inaccurately.	Identifies the main problem and subsidiary, embedded, or implicit aspects of the problem, and identifies them clearly, addressing their relationships to each other. Identifies not only the basics of the issue, but recognizes nuances of the issue.

2) Identifies and presents the STUDENT'S OWN **perspective, hypothesis or position** as it is important to the analysis of the issue.

Emerging ***Developing*** ***Mastering***

Addresses a single source or view of the argument and fails to clarify the established or presented position relative to one's own. Fails to establish other critical distinctions.	Identifies, appropriately, one's own position on the issue, drawing support from experience, and information not available from *assigned* sources.

3) Identifies and considers OTHER salient **perspectives and positions** that are important to the analysis of the issue.

Emerging ***Developing*** ***Mastering***

Deals only with a single perspective and fails to discuss other possible perspectives, especially those salient to the issue.	Addresses perspectives noted previously, and additional diverse perspectives drawn from outside information.

4) Identifies and assesses the key **assumptions**.

Emerging ***Developing*** ***Mastering***

Does not surface the assumptions and ethical issues that underlie the issue, or does so superficially.	Identifies and questions the validity of the assumptions and addresses the ethical dimensions that underlie the issue.

5) Identifies and assesses the **quality of supporting data/evidence** and provides additional data/evidence related to the issue.

Emerging ***Developing*** ***Mastering***

Merely repeats information provided, taking it as truth, or denies evidence without adequate justification. Confuses associations and correlations with cause and effect. Does not distinguish between fact, opinion, and value judgments.	Examines the evidence and source of evidence; questions its accuracy, precision, relevance, completeness. Observes cause and effect and addresses existing or potential consequences Clearly distinguishes between fact, opinion, & acknowledges value judgments.

6) Identifies and considers the influence of the **context *** on the issue.

Emerging ***Developing*** ***Mastering***

Discusses the problem only in egocentric or sociocentric terms. Does not present the problem as having connections to other contexts—cultural, political, etc.	Analyzes the issue with a clear sense of scope and context, including an **assessment of the audience** of the analysis. Considers other pertinent contexts.

7) Identifies and assesses **conclusions, implications, and consequences.**

Emerging ***Developing*** ***Mastering***

Fails to identify conclusions, implications, and consequences of the issue or the key relationships between the other elements of the problem, such as context, implications, assumptions, or data and evidence.	Identifies and discusses conclusions, implications, and consequences considering context, assumptions, data, and evidence. Objectively reflects upon the their own assertions.

Contexts for consideration

Cultural/social Group, national, ethnic behavior/attitude	**Scientific** Conceptual, basic science, scientific method
Educational Schooling, formal training	**Economic** Trade, business concerns costs
Technological Applied science, engineering	**Ethical** Values
Political Organizational or governmental	**Personal Experience** Personal observation, informal character

Appendix 2 – First ChE Rubric

Guide to Rating Critical Thinking
Washington State University
School of Chemical Engineering and BioEngineering
2005

1) Identifies and understands the **problem**.

1	2	3	4	5	6
Cannot identify or understand the problem: "What are you asking for"	Identifies main problem: "This is what he wants us to do."	Understands the Problem: "This is what we need to do, and this is why"	Understands the problem and its implications: "If we did X it might cause Y"	Integrates concepts from other subjects: "We need to consider X, which we learned about in Y"	Full and complete understanding of the problem and its underlying theory: "Sure I can derive that from scratch! (on the back of my napkin in this restaurant without any references)"

2) Identifies and presents the STUDENT'S/Group's OWN **method** as it is important to the solution.

1	2	3	4	5	6
Doesn't know how to begin the problem: "Where do I start"	Approaches the problem by modifying a textbook example: "They did it this way, so if I make these small changes it will work for me."	Background supplies appropriate solution method: "This is how we usually solve this type of problem"	Recognizes problem may be unique: "Does the usual solution method apply?"	Can develop unique solutions from fundamental theory if needed: "If we go back to the fundamentals we can do it this other way."	Can develop a novel method worthy of publication (in a trade or academic journal): "No ones ever tried this before but it should work really well."

Guide to Rating Critical Thinking
Washington State University
School of Chemical Engineering and BioEngineering
2005

3) Identifies and assesses the key **assumptions**.

1	*2*	*3*	*4*	*5*	*6*
Uses equations that look like they might work:	Uses the correct equation: "We used eqn. X because that is what is used for this."	Recognizes the conditions for which an equation was developed and can modify the equation for different assumptions: "Lets add a component for turbulent flow"	Can correctly select assumptions for a system based on an analysis of the physical components: "We have open channel flow, so we can't use a no-slip condition for all surfaces."	Recognizes commonly idealized assumptions and can determine their applicability: "This is the 1% of the time when X doesn't apply."	Knows, from experience, when 20% is close enough. "3.14 is close enough for pi."

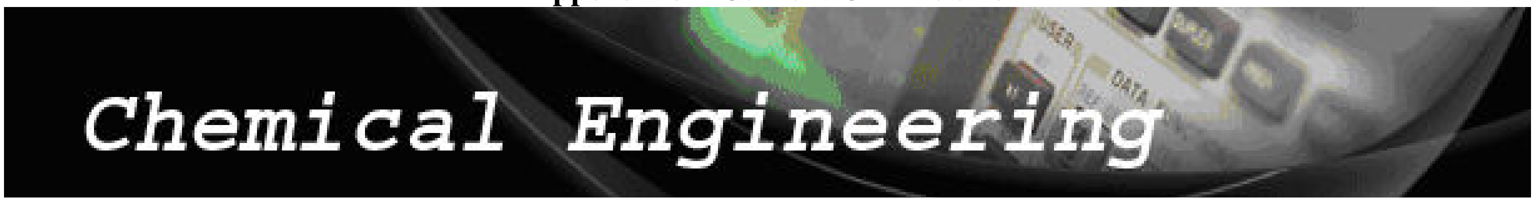
4) Assess the **quality of the solution**.

1	*2*	*3*	*4*	*5*	*6*
Does not care about the quality of the solution: "Well I got an answer."	Wants the "right answer": "What did you get?" "What does the answer book say?"	Questions physical validity of the solution: "Does my answer make physical sense?" "Is it realistic?"	Understands impact of physical components on the solution and how differing physical portions would impact the solution: "What if the pipe was bigger?"	Understands appropriate application and impact of errors throughout the system: "Well, are measurements are really only so good, so our solution is ......"	Can identify the impact of various fundamental theories upon the problem solution: "If we account for the compressibility it will change in this direction."

5) Comments and Observations

6) Questions Asked by this Person/Group

Appendix 3 – Current ChE Rubric



"Measure what is measurable, and make measurable what is not so." – Galileo

Critical Reasoning in Fluid Mechanics & Heat Transfer

Design Reflection: *Individual Assignment; 1-2 pages;*

For one of the situations below:

a. Imagine you are planning a custom-shaped, in-ground hot tub in your backyard.
b. A friend of yours has asked you to design a heating system for the above ground swimming pool in his back yard.
c. You need to design a system to transfer and cool hot, 98% Sulfuric acid from a mixing facility at your plant, at ground level, to a system on the third floor of one of the buildings.
d. You are replacing the filtration system for your Koi pond and don't want to use a kit.

Consider the flow and heat transfer systems for this.

c) What do you need to think about when designing the system? Why?
d) What pieces of equipment would need to be included? Why?

Your design reflection will be assessed using the attached *Guide to Rating Critical Thinking* and you'll receive 2 points for each section if you have a 1.5 average on all sections. For the mid-semester reflection you need a 3.0 average and for the end of the semester reflection a 3.5 average. One point bonus per section each time your average is 0.5 above these levels.

Please ask questions in class once you have read this so you understand the problem and how it will be rated and graded.

Rater	Paper #1	Paper #2 read	Paper 3# read

<table>
<tr><th>Dimension</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>Score</th></tr>
<tr><td>1. Problem / Question</td><td colspan="3">Does not identify a specific question or necessary and appropriate system or systems. The question or system, if identified, is confused or simplistic.

Little evidence of understanding of salient constraints (e.g, cost of water, available space, etc).

Little evidence that goals or potential/useful outcomes identified and understood.</td><td colspan="2">Identifies a somewhat focused question/goal that is interesting but not particularly challenging or is simplistic, tends to ignore essential constraints.

The problem/goal is vaguely defined and characterized. Consideration of goals or outcomes is vague or suggests important omissions of key considerations.</td><td colspan="2">Identifies a focused, unique, original question/goal that is challenging and well defined

Thoroughly understands constraints.

The question/goal is thoroughly defined and characterized.
.</td><td></td></tr>
<tr><td>2. Fluid Mechanics Principals / Equations
How chosen/appropriateness

Depth of Use / Integration

Completeness</td><td colspan="3">Analysis of fluid mechanics principles is absent, incomplete or inappropriate relative to the presenting problem—or insufficiently related to the challenge the project entails

There is little Interpretation of fluid mechanics principles, or there may simply be a restatement of inherited facts.</td><td colspan="2">Analysis of fluid mechanics principles is essentially correct; perhaps some is off tangent or barely related to the presenting problem, but generally in the vicinity of the challenge the project entails

Interpretation is adequate and clear, though perhaps not fully integrated with other sources or perspectives. Barely extends, if at all, beyond routine exploration.</td><td colspan="2">Analysis of fluid mechanics principles is thorough and correct.

Interpretation is well integrated with other chemical engineering principles, sources and professional perspectives.</td><td></td></tr>
<tr><td>3. Heat Transfer Principals / Equations
How chosen/appropriateness

Depth of Use / Integration

Completeness</td><td colspan="3">Analysis of heat transfer principles is absent, incomplete or inappropriate relative to the presenting problem—or insufficiently related to the challenge the project entails

There is little Interpretation of heat transfer principles, or there may simply be a restatement of inherited facts.</td><td colspan="2">Analysis of heat transfer principles is essentially correct; perhaps some is off tangent or barely related to the presenting problem, but generally in the vicinity of the challenge the project entails

Interpretation is adequate and clear, though perhaps not fully integrated with other sources or perspectives. Barely extends, if at all, beyond routine exploration.</td><td colspan="2">Analysis of heat transfer principles is thorough and correct;

Interpretation is and well integrated with other chemical engineering principles, sources and professional perspectives.</td><td></td></tr>
<tr><td>4. Fluid Mechanics Assumptions</td><td colspan="3">There is little or no synthesis from literature; or what is presented is incoherent or patched together without explanation or demonstration of underlying fluid mechanics assumptions.

Assumptions tend to be confused or perhaps contradictory. Key aspects of the challenge are neglected.</td><td colspan="2">Application of material discerned from literature or outside reading is adequate in scope and accuracy, though perhaps slightly confused at times or partially inaccurate.

Sometimes questions and attempts to support the validity of assumptions.</td><td colspan="2">Application of material discerned from literature as well as from outside reading is complete and accurate.

Questions and supports the validity of assumptions.</td><td></td></tr>
</table>

5. Heat Transfer Assumptions	There is little or no synthesis from literature; or what is presented is incoherent or patched together without explanation or demonstration of underlying heat transfer assumptions Assumptions tend to be confused or perhaps contradictory. Key aspects of the challenge are neglected.	Application of material discerned from literature or outside reading is adequate in scope and accuracy, though perhaps slightly confused at times or partially inaccurate. Sometimes questions and attempts to support the validity of assumptions.	Application of material discerned from literature as well as from outside reading is complete and accurate Questions and supports the validity of assumptions.	
6. Other Assumptions	There is little or no synthesis from literature; or what is presented is incoherent or patched together without explanation or demonstration of underlying heat transfer assumptions Assumptions tend to be confused or perhaps contradictory. Key aspects of the challenge are neglected.	Application of material discerned from literature or outside reading is adequate in scope and accuracy, though perhaps slightly confused at times or partially inaccurate. Sometimes questions and attempts to support the validity of assumptions.	Application of material discerned from literature as well as from outside reading is complete and accurate Questions and supports the validity of assumptions.	
7. Equipment Specification	Improper or superficial equipment selection. No attempt at sizing, evaluating alternatives, etc. Equipment selection demonstrates little depth, attention to or understanding of professional conventions. Simple list of equipment.	Proper equipment selection, but limited in terms of evaluation of alternatives, sizing, etc. Equipment selection demonstrates some use of professional convention (rules of thumb) Some systems level thinking.	Equipment selected and optimally sized after a thorough evaluation of alternatives. Thorough use and understanding of appropriateness of professional convention. Integrated systems thinking	
8. Solution Quality	Solutions are missing or inaccurate / unreasonable. The implications of the solutions are absent.	Solutions are reasonable, though perhaps incomplete or limited. Solutions relate to the design problem and arise from the analysis presented, though there may be gaps or redundancies. May include speculation about implications -- mostly plausible, but not necessarily reasonable useful or creative.	Solutions are accurate, appropriate, thorough, and clearly linked to design problem. Solutions and recommendations are qualified, balanced and can be extended to other situations.	

9. Organization and Communication	Presentation of problem, analysis, solution and interpretation seems haphazard, inconsistent, or misleading; one or more elements may be missing or confused Organization of ideas / multiple errors obscure meaning, and may misinform or mislead audience. Many parts seem difficult for the audience to follow. Communication style, written and/or oral, is not appropriate to this discipline, or is confusing. Does not use language of the discipline, or uses it incorrectly. Frequent errors may obscure ideas. Media and format are poor choice for content; some materials confusing or distracting, or served as filler. Communicates little or no engagement or ownership of the work.	There is a discernable progression from problem to analysis, solution and interpretation, linked to the problem and solution. Presentation is adequate for intended audience, though there may be occasional gaps, errors, or inconsistencies which require effort from audience in order to understand. Communications style, both written and oral, is appropriate to this discipline; though not at a professional level, communication is adequate Incorporates some language of the discipline, though imperfectly. Some errors may distract audience. Appropriate media and format used for content. Most materials clear and pertinent Communicates some engagement and ownership of the work	Progression from problem to analysis, solution and interpretation is concise, creative, and clearly ties problem to solution and implications. Needs and interests of intended audience effectively inform presentation's approach and organizations. Audience seems well able to follow the presentation. Communications style, both written and oral, is appropriate to this discipline, and is polished, professional, and virtually error free. Uses language of the discipline fluidly and effectively. Appropriate media and format used for content; all materials clarified, with pertinent or high interest information. Clearly communicates engagement and ownership of the work.	