Modeling a Martian Water System

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INTRODUCTION

Who are my students?

I have taught almost every secondary mathematics course, physics, physical science, engineering, computer programming, engineering and space science. What I learned from this experience is that all of the courses had some relationship to the real world. I also learned that, in isolation, each course seems so distant from reality. The goal of this unit is to unite concepts from all of these courses into a unit that will allow students to see the relationships between the real world and the world of academics.

The students in my classes are labeled "gifted and talented." What this means is beyond me; the students are motivated and confident in their ability. Most of them have reasonable perspectives about what they want to be and what will be required to reach their goals. I'd rather set high expectations rather than label the students. This makes this unit be tailored for any student who is thinking about their future and the future of society.

What this unit is about

The "real world" that I will use is hardly real. This unit will take the students to a world millions of miles away in distance and decades in the future. They will design a water system for a futuristic Mars settlement. The idea is to allow students to dream about what could be their future. The reality comes in when they realize the difficulty of the task.

The real question is, *What is this curriculum unit?* It is *not* complete. It does not contain all the material necessary to teach the unit. It only discusses initial resources that can start teachers and students in the "right direction." What the right direction is open to question. Hopefully, the right direction may be different for each student.

The students will not become experts on Mars or water systems. There is much disagreement among those who are considered experts in their field in these areas. There are many areas where there is even disagreement about the basic body of knowledge. The best possible scenario is that students will understand that there are more questions than answers and that "answers" only create more questions.

The students will need a large database consisting of much material and a number of simulations. This *could* be presented in lecture form. My approach will be different. Rather than be "a sage from the stage," I am choosing to be a "guide from the side."

While this all sounds good, it will require an enormous amount of energy beyond the unit presented here. I am in the midst of downloading hundreds of articles from websites. I also plan to develop a number of simulations using multimedia software. Students will receive a CD rather than a reading list. This is the twenty-first century. We need to go beyond nineteenth century teaching methods.

Creative Problem-Solving

The unit will begin with the students being exposed to creative problem-solving techniques. The students will not only need to think "outside the box"; they will need to think outside of the Earth. Following rote techniques will not be sufficient. Students need to think in original ways.

Creative thinking, however, is not clearly defined. There are a huge number of resources that address creative thinking. Therefore, there are many strategies that depend upon the definition of the author. Almost all of these strategies are discipline-based. They are narrow in their application. There are several sources listed in the annotated bibliography. Looking at these sources will broaden the perspectives of the students.

Since this unit will cover so many disciplines, a creative problem solving strategy is needed to handle the broad nature of the topic. Advanced Systematic Inventive Thinking (ASIT) provides such a strategy. The goal of ASIT will be to teach students to think about problems in original but organized ways. Unfortunately, ASIT is a commercial venture. Using it will depend on adequate funding being secured, $1,000 for an unlimited school license. (See the Annotated Bibliography.) This unit will assume that such funding can be secured.

WATER: ITS QUALITY AND TREATMENT

Earth as a base of knowledge

Students will then study water as it pertains to Earth. Several authoritative sources will be available to students. The students will need to understand the amount of water needed for different uses including drinking and home use, food production, and manufacturing.

The use of water affects its quality. Water quality will often be compromised by its use. This creates the need for wastewater treatment to make its quality adequate for reuse. The concept to be taught here is that, after use, the water should be returned to its original quality.

The quality of the water affects its use. Drinking water, for example, must be safe. Chemicals, and dangerous biological agents must be removed. Water treatment concepts will be a very important component of the unit.

Engineering Principles

On Earth there are a multitude of water treatment methods employed. The methods used depend on the materials that are to be removed from the water. For this unit, we will select a small subset of these techniques. Students will study these techniques to gain a starting point for their project. There are certain engineering principles that all techniques have in common.

The first principle is **time**. The treatment techniques do not happen instantaneously. This limits the amount of water that can be treated in a certain time period. To counteract this limitation, requires large and *parallel* systems.

The next principle is **effectiveness**. No technique can remove all of any type of waste. In water treatment terms, the offending item is measured in milligrams per liter (mg/L). The term used is an acceptable limit. If 99.9999% of an offending substance needs to be removed, and the technique removes only 99.99% of the substance, then several stages must be used. This requires that the technique be in several stages in *series.*

The third principle is **removal**. The offending substances must be removed. What is to be done with them? On Earth, these substances are often diluted and placed in the ecosystem (someplace else). On Mars, the inhabitants are in a small habitat (relative) to earth and there is not convenient ecosystem outside the enclosure to dilute pollutants. There is not "someplace else." In actuality, as the Earth becomes more populated, this problem becomes more acute. This is one of the prime reasons that this unit was developed.

Treatment Strategies

Once the basic concepts are understood, the students will need to choose the best techniques to remove unwanted constituents from water. They will then need to modify them to meet specific concerns. Table 1 (Montgomery, 80) represents some of the major techniques used in separation.

Table 1: Separation Techniques

Process	What It Is	What It Removes
Adsorption	Particles stick to another substance.	Algae, Pathogens, Chloroform, Fluoride, Humic Acids, Mercury, Phenol
Coagulation	Fine particles stick to themselves and aggregate into larger particles.	Algae, Pathogenic Bacteria, Clays, Humic Acids, Mercury
Distillation	Water is removed through boiling.	Dissolved Salts
Freezing	Water is frozen off.	Dissolved Salts
Ion Exchange	Ions are transferred from a liquid to solid form.	Calcium, Mercury Nitrates, Dissolved salts, Sulfates
Oxidation	This is used to remove odors and bad tastes.	Ferrous Iron, Phenol
Ozonation	Ozone is an effective killer of pathogens	E. Coli Bacteria, Poliovirus 1
Reverse Osmosis	Membrane lets water through under pressure.	Calcium, Chloroform, Humic Acids, Ferrous Iron, Nitrates, Dissolved Salts
Sedimentation	Uses gravity to separate out solids	Algae, Pathogenic Bacteria, Calcium, Clays, Fluorides, Humic Acids, Mercury, Dissolved Salts, Sulfates
Straining	Substances are “screened” off.	Algae

OFF TO MARS

It is now time to leave the Earth. We’re off to Mars! Mars is a very different place than the Earth. It is so cold that nearly half of the atmosphere freezes during Martian winters. The atmosphere is less that one percent of the density of the Earth. There is no liquid water at the surface. Mars appears to be a hopeless place to live.

Things look much better if we look below the surface – literally. There is ample evidence that there are vast water reservoirs below the surface. That water is probably frozen, but it’s water. It may be stored in cracks in the rock, but it’s water. Water will be necessary to keep the settlers alive. It will be up to the students to determine how to get that water and make it usable. Students are to design a system that will produce, purify, recycle, and replace enough water for 1,000 settlers. The water must be used for human consumption, food production and preparation, and for emergencies.

Water Treatment Systems

There will be a water system. Each component is dependent on the other components. There is flow between them. The components and the interfaces between them will become more complex as research is done. The whole system will be enclosed in a dome. This makes the system closed. A simplified system is illustrated in Figure 1 below:

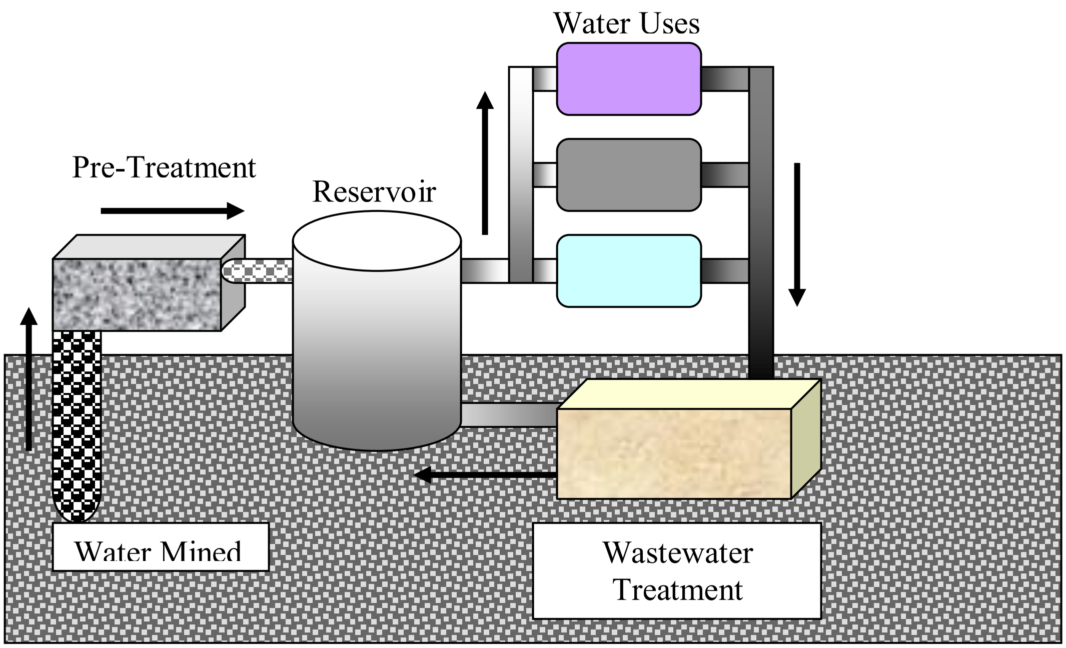

Figure 1: Simplified Flow Diagram

Let's consider the drinking water and the food production. We will assume that the food production will actually be two objects, plant growth and a fish farm. Therefore, there will be three objects. These are partially described below:

- Drinking Water: Humans need clean and safe water. Questions of chemical and biological contaminants must be answered. The wastewater produced through human consumption is not reusable without decontamination.
- Plants: Plants need water that contains nutrients. They use some of the water and nutrients. There is very little if any contamination caused by the plants.
- Fish Farm: The fish will need nutrients. There is both chemical and biological contamination of the water. The water needs a purification system.

The safest system is to keep each of the objects isolated from the other objects. Each system takes some water in and recycles its own water. Figure 2 below illustrates this concept for human consumption. Similar systems could exist for other water uses.

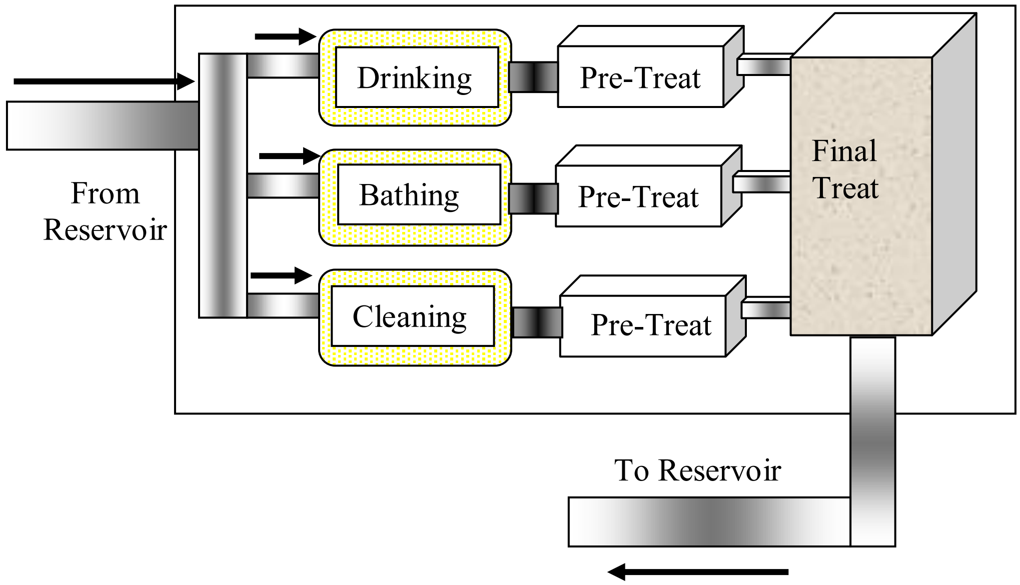

Figure 2: Human Consumption

The safest system is not necessarily the most efficient. For example, plants need nutrients that are contained in the waste from the human consumption system and the fish farm. As the plants use up the nutrients, they partially prepare the water for humans and fish. With some treatment, the water can demonstrate symbiosis. This could make this part of the system look like Figure 3 below.

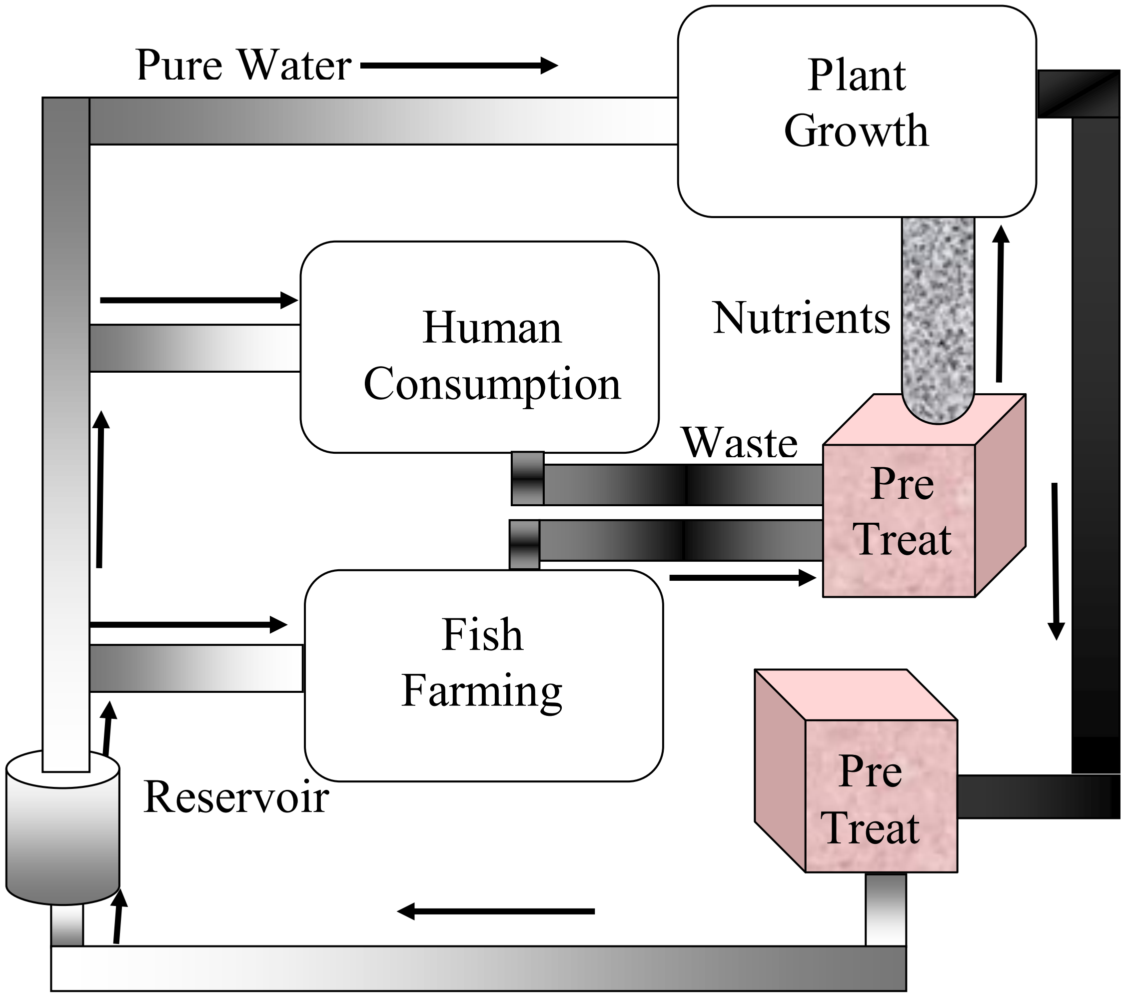

Figure 3: Reusable "Wastes"

The need for safety starts with the reality that the settlement is a closed system far from the relative security of Earth. People are in close proximity. Any communicable disease can quickly spread and literally "wipe out" the settlement. Chemical contamination, especially by carcinogens, can be devastating. Leaving the settlement cannot solve these crises. There is literally nowhere to go.

The efficiency of operation is the next critical question. Mars is a very cold and forbidding place. Survival requires the creation of an artificial environment. This will require an enormous amount of energy production. There are no fossil fuels. Mars receives only about 40% of the solar energy that the Earth does because of its distance from the sun. The transportation of fuel from the Earth is probably prohibitively expensive. The only practical solution is to produce the energy *in situ* (on-site).

The trade-off is between safety and efficiency. How will this trade-off be solved? It reminds me of the famous line from New York City. "How do I get to Carnegie Hall?" "Practice, practice, practice!"

In this unit, the students will choose between three possible system configurations. These systems will be given names. All of the systems get their water from the common reservoir. This water is pre-treated before going to the various users.

The first is the common system. It uses one common wastewater treatment process before returning to the reservoir. This system has a lower cost because treatment processes are not duplicated. This system can be very dangerous if hazardous wastes that cannot be treated get into the overall system. On Mars, the small size and the closed nature can lead to catastrophic results from any such event. The common system is illustrated in Figure 4A.

The next is the separate system. Each use has its own wastewater treatment unit. This will require an additional reservoir for each separate user. No water can be returned to the main reservoir until it meets a stringent set of requirements. The separate system is very expensive and very safe. The separate system is illustrated in Figure 4B.

The final system is the hybrid system. This is a compromise between the common and separate systems. Which treatments should be common and which should be separate will depend upon the water use and the waste products introduced. A good common sense rule is to treat carcinogens and pathogens separately. The hybrid system is illustrates in Figure 4C.

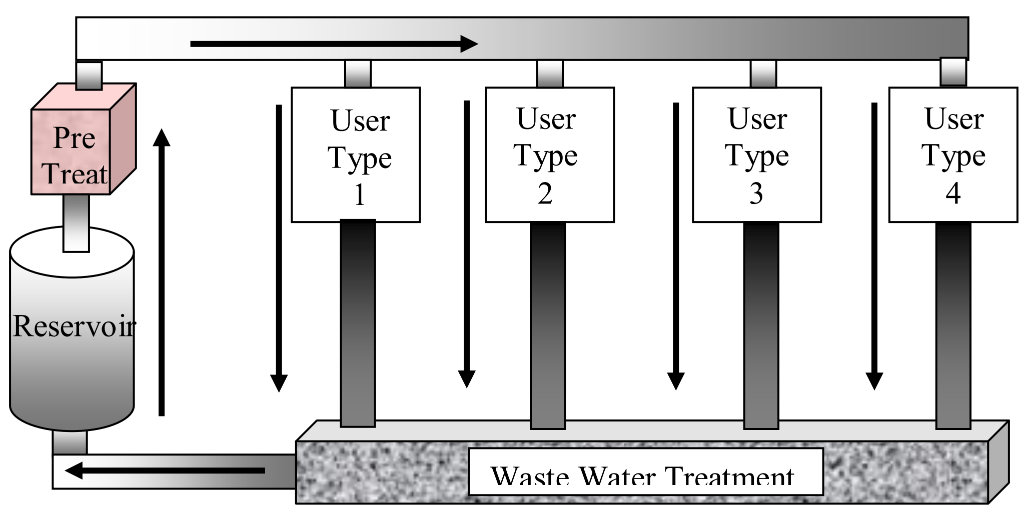

Figure 4A: Common Treatment

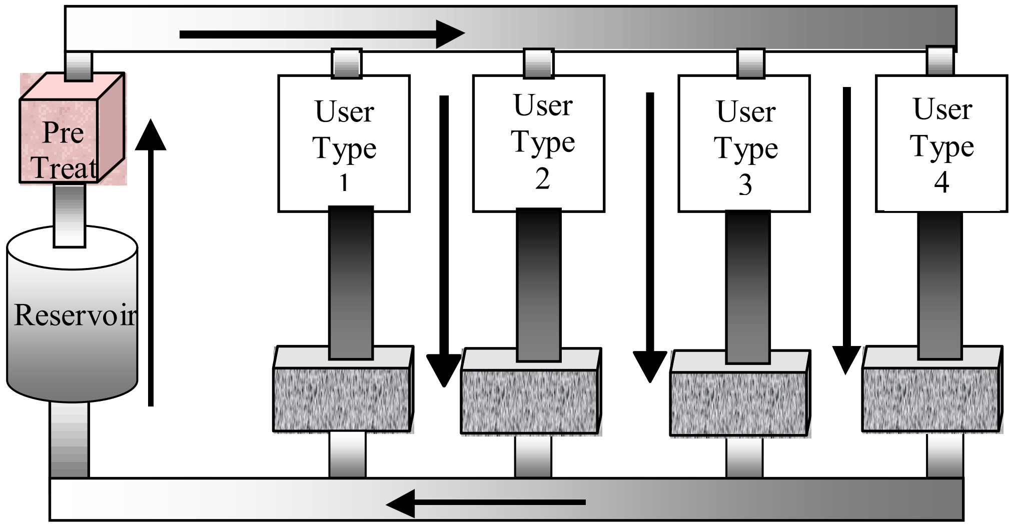

Figure 4B: Separate Treatment

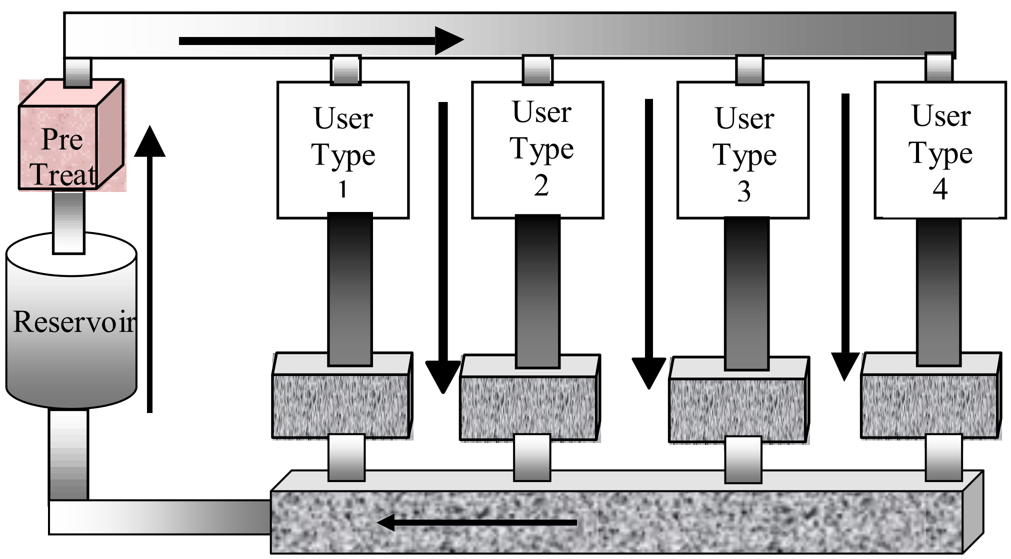

Figure 4C: Hybrid Treatment

The example above is just that – only an example. The whole project needs to be studied as a system. The work is too much for any one student. The only reasonable approach is to be divided into teams. The teams will be responsible for one "object." Each team will use the best data available. This will require much research. Initial Internet sites have been downloaded for each team. These sites are identified by teams in the annotated bibliography.

OBJECT ORIENTED PROGRAMMING

The concepts have a direct implementation in computer programming. This implementation is called object oriented programming (OOP). This project offers an excellent introduction to OOP.

The only way that students can tackle the project is through teams. Each team will design one component. These components are the "objects" of OOP. The objects consist of information (data) and operations (functions). The internal data and functions are only of interest to the team in charge. In OOP, this data and these functions are considered "private." The other objects do not have access to them. There must be information and actual materials shared between the objects. The functions that are shared are called "public interfaces."

A major part of the project will be the negotiations in the design of these interfaces. There are advantages and disadvantages to various forms of interfaces. The example below will illustrate some of the trade-offs.

THE TEAMS

This unit assumes that there are 24 students in a class. That assumption allows will be six teams of four members each. If the class size is smaller or larger, the teams will be reconfigured. It is very important that the teams contain about four team members. This will allow for effective interaction within a team. For a team of four, the team members will have the following primary responsibilities:

- Data Research Specialist (DRS): This member will be responsible to make sure that the data used in decision-making is the most accurate possible.
- System Design Specialist (SDS): This member will be responsible for the design of the object program.
- Operations Specialist (OPS). This member will make sure that what is proposed works.
- Reliability and Safety Hazard Engineering Specialist (RASHES): This member will test the response when something goes wrong.

Since each team has a similar structure, the member of each team can also be a member of a specialty. This requires everyone to be in two teams. It does not end there. The results of the project need to be communicated to others. Each team member can therefore, have at least a third responsibility:

- Written report (WR)
- Multimedia report (PR)

- Oral Presentation (OR)
- Model (MOD)

Team Strategies

This problem arose several years ago during projects. I created what I call Dynamic Interactive Grouping (DIG). Students will be in at least three groups. They will need to meet among the various groups as the occasion arises. They may have to form more groups depending on the need. This indeed can create chaotic situations. Chaos is the bane of engineers. Creating order from chaos is their primary role. Order may be fleeting. At least for a while there may be order.

This raises a major philosophical issue with object-oriented programming. OOP works well in a static system. As the system becomes more dynamic and interactive, it becomes more difficult to modify the tasks. There are two almost contradictory concepts, stability and reality. Stable conditions are easy to program. Dynamic systems create problems. To introduce this concept, each team will need to try to develop a system that must respond to random events. This randomness will introduce major problems.

Students must realize that they are not producing reality. They are only modeling reality. While they are learning much, they must realize the limitations of what they are learning. Hopefully, this will translate into a desire to learn more.

Team Responsibilities

Based on the above discussion, initially the students will probably be divided into six teams. The primary functions for each group are described below. Each team will start out with an initial set of tasks and data. The responsibilities for each team are described below:

Water Exploration Team (WET)

This team will find the best way to meet the water needs of the other teams. The team will have to develop techniques for "mining water" from below the surface of Mars. They will be attempting to do this while there is strong disagreement about the existence of underground water. Students in this team must feel comfortable in an imperfect world.

The water will probably contain mineral and chemical contaminants. Table 2 (Cattermole, 10) represents data collected from NASA's Viking 1 and Viking 2 Landers. The average is probably a good estimate.

Table 2: Mars Surface Composition in % Weight

Major elements	Viking 1 Lander	Viking 2 Lander	Average
SiO_2	44.7	42.8	43.7
Al_2O_2	5.7	20.3	13
Fe_2O_3	18.2	1.0	9.6
TiO_2	0.9	5.0	3
MgO	8.3	< 0.3	4.3
CaO	5.6	6.5	6.1
K_2O	< 0.3	0.6	0.5
SO_3	7.7		3.9
Cl	0.7		0.4
H_2O	1	1	1

Plants for Settlers Team (PST)

This team will determine both the type and quantity of food. PST will provide WET and WART with water requirements and treatment required for reuse. This area will require team members who have an interest in nutrition. They will have to make assumptions about nutrition needs on Mars.

The nutrients needed by different types of plants vary. The plants also can release biological by products. This team must deal with both the nature of the water entering and the treatment necessary to remove any unwanted byproducts.

Fish for Food Team (FFT)

This team will have the primary responsibility of providing protein for the settlers through the growth of fish. They will need to provide the nutrients and water conditioning necessary to maximize fish growth. The selection of types of fish that are an efficient food source will be difficult. Fortunately, fish farming is becoming a very large industry on Earth. FFT will provide WET and WART with water requirements and treatment required for reuse.

There are several quality conditions that must be met. The water has to have a pH level close to 7; be highly oxygenated; have the temperature be correct for the chosen fish; and have very low ammonia content.

Water Accumulation and Recycling Team (WART)

This team will provide treated water to each of the other teams and treat used water from all other teams. There are many sources that exist on the Internet. Unfortunately, most of the sites are commercial. Students on this team may require field trips to local wastewater recycling operations. This team is ideal for students that need real, concrete examples.

Manufacturing and Supplies Team (MAST)

This team will provide water for manufacturing and supplies processes. This may require water with different properties. The worst-case scenario may be in the area of semiconductor manufacturing because of its requirements for extremely pure water. Team members on this team, therefore could be the "tekkies." MAST will provide WET and WART with water requirements and treatment required for reuse.

Human Use Management and Needs (HUMAN)

This team will determine the quality of the water needed by humans for drinking water, bathing, cleaning, and other uses. They must also determine the quality of the wastewater produced by human excretion, bathing and cleaning. There probably will be many compromises in how bathing and cleaning are done to prevent harmful and difficult to remove waste products.

STUDENT LEARNING AND THE UNIT DESIGN

The first issue facing the design of this unit is the question of what students perceive. There is often a significant difference between what is taught and what is learned. Student misunderstanding is a significant issue. Wiggens and McTighe state:

> Even conventional testing can reveal failures to understand. Consider this result in mathematics. Most teenagers study Algebra 1 and get passing grades. Yet the National Assessment of Educational Progress (NAEP) results show that only 5 percent of U.S. adolescents perform well at tasks requiring higher-order use of Algebra 1 knowledge (NAEP, 1988).
>
> ... To see how easy it is to misunderstanding things we all know, consider the entry point question in the previous chapter, "Why is it warmer in summer and colder in winter?" Every student in the United States has been taught basic astronomy... But even when Harvard graduates were asked the question... we discover that few can correctly explain why it is colder in winter than in summer (Schneps, 1994). They either have no adequate explanation for what they claim to know, or they provide a plausible but erroneous view (i.e., the weather changes are due to the earth being closer to or further from the sun).
>
> ... Teachers who take a proactive approach to design can combat the likelihood of deeply rooted misconceptions and the potential for misunderstanding. To successfully engineer understanding, educators have to be able to describe what it

> looks like, how it manifests itself, and how apparent understanding (or misunderstanding) differs from genuine understanding (43).

The goal of this unit is to minimize misconceptions about all the issues covered. As the project unfolds, considerable effort must be made to catch misconceptions in their infancy and cure them. This will require active teacher intervention. I once remember a student in a Mars colonization project proposing that Mars have a professional football team. After the shock wore off, I remember replying with a question: "Whom would they play?"

The Big Question: Water on Mars?

The unit is based on a huge assumption – that there is an adequate supply of water for the settlement below the surface of Mars. The concept that there once was abundant water on the surface of Mars is generally accepted from evidence gathered in the past thirty years. It is also generally accepted that frozen water exists at the polar ice caps on Mars. At the writing of this unit, research is being conducted to determine if there is water below the surface and if so, how much and where? On February 23, 2002, the *Houston Chronicle* reported that the NASA Mars Odyssey spacecraft began "scanning the rugged surface of Mars with cameras and other instruments in search of elusive ground water." The article states that the spacecraft is studying possible landing sites for robotic landers to be launched in early 2004 (Carreau, 2002).

In *The Case for Mars*, Zubrin describes both the problem and promise of water below the surface:

> Above all, astronauts will seek out easily extractable deposits of water ice or, better yet, subsurface bodies of geothermal heated water. Ice or water is key, because once water is found, it will free future Mars missions from the need to import hydrogen from Earth for rocket propellant production, and will enable large-scale greenhouse agricultural to occur once a permanent Mars base is established (11).

The real question is: *Should we wait for irrefutable evidence of water on Mars before beginning the unit?* Certainly, we should not risk human life before very clear and compelling evidence that water exists and can be gathered with both the quantity and quality necessary to sustain the settlement. We can and should proceed with the project, however, with the assumptions that such a supply does exist and that it is recoverable.

The issue becomes a question of risk and consequences. The risk of creating a model that will not actually be used is very, very high. In fact, the probability of the model being used in a real settlement is between zero and none. The consequences of this risk are almost nil. The consequences of not implementing the unit are great. Students will have lost an opportunity for a valuable learning experience.

Indeed there is one verified source of water on Mars. It is in the soil. Zubrin estimates that the soil contains 3% water. Using the heat from a nuclear reactor, a 100 KW *reactor* could create "up to 14,000 kilograms per day of water if the reactor's waste heat is used to bake the dirt" (Zubrin, 189).

Just how much water is needed for the Mars settlement? In *World Resources 1996-97* Data Table 13.1 on page 307, the amount of water used per capita in the United States for one year is 1,870 cubic meters. For 1,000 settlers, this becomes 1.87 million cubic meters per year. A very safe water estimate would be to store enough water to last two years. This would mean 4 million cubic meters of water. One cubic meter of water has a mass of 1,000 kilograms. Thus the settlement would need about 4 billion kilograms of water. Using the heating soil technique explained in the previous paragraph, it would take almost 1,000 years to produce enough water. Clearly another water source is needed!

The Question of Systems and Modeling

We will be modeling environmental systems using computer simulations. Models simplify reality. Care must be taken that the models do really describe reality. This is a major problem, particularly when we are modeling a system that has never been visited by humans. (Some people, however, believe that humans are descendants of Martians. That is *way* out of the scope of this unit.)

Andrew Ford states the problem this way:

> The premise of this book is that computer simulation models can help us develop our instincts for managing environmental systems. We build a mathematical model to capture the key interrelationships in the system; then we conduct experiments with the mathematical model to sharpen our instincts for managing the simulated system. But you should understand that computer models require a tightly disciplined approach. They require us to be clear and explicit about our assumptions. A well-documented model will allow others to appreciate the assumptions and the conclusions drawn from our experiments. Careful documentation will also permit others to challenge our underlying assumptions and to build improved models with more realistic assumptions (5).

The philosophy of the previous quote is crucial in a student's education. The students are successful if they provide a step in the process to the development of a water system for Mars. If they or others can use what they develop to further the process, they have made a valuable contribution to humanity. If the step leads to a dead end, at least they have made a valuable contribution to their own education.

A Word about Object Oriented Programming

Most texts on the subject of object oriented programming (OOP) concentrate heavily on the programming. OOP is, however, much more than that. It is a method of modeling. Wolfgang Haerle describes one term, encapsulation, this way:

> One of the primary advantages of using objects is that the object need not reveal all its attributes and behaviors. In good O-O (OOP) design (at least what is generally accepted as good), an object should only reveal the interfaces needed to react with it. Details not pertinent to the use of the object should be hidden from other objects. This is called *encapsulation* (20).

This is one of the clearest explanations that I've found on the concept. Even it is not very clear. For modeling, the goal of encapsulation is to allow several teams to work on different parts of a project without messing up the work of every other team. If data is not kept separate, many teams might use the same variable name. If one team changes the variable value, all of the other teams may calculate the wrong value. By keeping what is done by each team done separate (encapsulated), all teams are isolated from "a virus" spread by another team. This is the same concept as isolating all parts of the Mars water from all other parts. OOP has a direct analog in real world systems. That makes it advantageous in solving real world problems

LESSON PLANS: UNIT SCOPE AND SEQUENCE

This unit is designed for a twelve-week period. Since most schools are on Block Scheduling, this converts to about 25 classes. This allows for five necessary and unnecessary interruptions that always occur in public schools (20% overhead). The unit is divided into five major sections. The lesson plans for each section are:

- **Introductory Information for All Students**: This section contains introductory material that is discussed in the class. The students will also have access to materials downloaded from the Internet along with all of the sections on a CD. Seven classes are allocated for this section. Each topic below will take one class period. The areas covered will be:

    - **An Overview of Mars**: The students will view *Mars: Past, Present & Future.* The DVD is 85 minutes long. The students will fill out answers to questions as they view the DVD.
    - **The Water Cycle on Earth and How Mars Is Different**: This topic will cover the hydrologic cycle on Earth. It will also discuss the artificial cycle for Mars. The students will be given questions to answer on the topic.

    - **Water Use Estimates for Mars Based on Earth Use**: Data from various sources will be used to project possible water use on Mars. The students will make calculations on the needs of a Mars colony.
    - **Water for Human Consumption**: Students need a basic understanding about the quality of water necessary for human consumption and the contamination introduced by that consumption. This will begin students understanding of closed systems and recycling. The students will design a simple block diagram for human consumption and recycling.
    - **Other Water Uses**: Different uses require different purities and introduce different contaminants. This section is designed to broaden student understanding of the problem. Students will attempt to develop a simple block diagram.
    - **The Question of Energy**: Energy is needed to do anything on Mars. Even though people complain on the Earth, energy on Mars will cost much more on Mars. The students will state the advantages and disadvantages of different energy systems.
    - **Testing Understanding**: The students will answer questions on the various topics in this section. The test will explicitly follow a review sheet. The goal is a basic understanding of the material.

- **Problem Solving**: The students will learn techniques in problem solving by using the Advanced Systematic Inventive Thinking (ASIT) course. They will also study other techniques in creative problem solving. This will require two classes.
- **Team Creation**: The concepts of teams and the object-oriented approach will be discussed. The teams will then be created based on materials provided previously in this unit. This will take approximately two classes.
- **The Project**: This is the heart of the unit. Students will research a number of areas. The areas for research will be allocated among various teams. The teams will meet frequently to make sure the teams are "on the same page." All of the efforts of the teams will be used to create a computer model for the water system. This will require about ten classes.
- **The Presentation**: The teams will work on a final presentation to be presented before a panel of experts in the field. The preparation and presentation will take three classes.

ANNOTATED BIBLIOGRAPHY

The Annotated Bibliography below is a partial list. The categories that I chose as labels are somewhat artificial. Many of the articles, books, and web sites could easily be placed in other categories.

Teacher Resources

The following resources are not readily available at a web site. A summary of the material in this section is provided in the section on lesson plans. As a teacher, you may want to use these resources to supplement your knowledge.

The sources provided for under the student resources are representative of the web sites available. The best way to use these is to download them for CD distribution.

Mars Overview

Cattermole, Peter. *Mars The Mystery Unfolds.* New York: Oxford University Press, 2001.
This book provides an authoritative overview of Mar using data from several Mars missions.

Mars: Past, Present & Future. Finley-Holiday Films. <http://www.finley-holiday.com/> (5 April 2002).
This DVD video provides both a historical and visual perspective on Mars. The graphics are at a very high level. Students can get a real understanding of Mars. There is considerable coverage on the question of water. The DVD costs $24.99 plus shipping and may be ordered online from

Problem Solving

Advanced Systematic Inventive Thinking Premier Course. < http://www.start2think.com > (12 April 2002).
This site costs money. For an individual, it costs $29. It also is by far the best online material that I have ever seen. The online course lasts about two hours. It provides a refreshingly new way to look at problems. The cost for an unlimited site license in a school is $1,000. I strongly recommend it for all high school teachers and students.

Unit Design

Wiggens, Grant and McTighe, Jay. *Understanding by Design*. Alexandria, Va.: Association for Supervision and Curriculum Development, 1998.
This book provides an authoritative explanation of curriculum design and assessment of students. It specifically highlights unit design.

Object-Oriented Programming

Ford, Andrew. *Modeling the Environment.* Washington, D.C.: Island Press, 1999.
This book provides modeling techniques for dynamic modeling of environmental systems. While not specifically object-oriented programming, it provides bridges between problem-solving programming and environmental issues.

Weisfeld, Matt. *The Object-Oriented Thought Process.* Indianapolis, IN: Sams Publishing, 2000.
This book provides an overview of the object-oriented thought process. It offers explanations of object-oriented programming rather than code.

Water Resources: Earth

Cohen, Joel E. *How Many People Can the Earth Support?* New York: W.W. Norton & Company, 1995.
This book provides techniques for projecting the population that the Earth's resources can support. Water is clearly one of the most important resources.

The Underground Subject: An Introduction to Ground Water Issues in Texas. Texas Water Commission. Austin, TX: The Texas Water Commission, 1989.
Describes the how and why of ground water in Texas. There is also a brief explanation of water contamination.

World Resources: A Guide to the Global Environment 1996-97. World Resources Institute. New York: Oxford University Press, 1996.
This is a data book published jointly by the World resources Institute, United Nations Environment Program, United Nations Development Program and the Word Bank. It is an objective analysis of world resources.

Water Quality and Use

Bridwell, Raymond. *Hydroponic Gardening.* Santa Barbara, CA: Woodbridge Press Publishing Company, 1998.
This book offers a clear and understandable guide to hydroponic gardening on Earth. Most of the ideas are directly applicable to Mars.

Symons, Dr. James M. *Plain Talk About Drinking Water.* American Water Works Association. 2001.
This book provides answers to questions about the quality of drinking water. It also describes its average use.

Water Production and Purification Systems

Carreau, Mark. *Houston Chronicle.* “Mars Craft Searches for Water.” 23 February 2002. Section B.

Water Treatment Principals and Design. James M. Montgomery Consulting Engineers. New York: John Wiley and Sons, 1985.
This book is one of the most complete and authoritative texts on water treatment. It is also very expensive. The book costs $199.95 new.

Zubrin, Robert. *The Case for Mars.* New York: The Free Press, 1996.
This book is considered one of the most authoritative books on creating a permanent settlement on Mars. There is a thorough discussion on water production and recycling.

Student Resources

Problem Solving

Creative Problem-Solving. < http://www.arachnoid.com/lutusp/crashcourse.html> (12 April 2002).
This site provides a series of examples of creative problem solving.

Introduction to Physical Science, 122. 26 October 1995. <http://www.hcc.hawaii.edu/hccinfo/instruct/div5/sci/sci122/newton/Gravity/probsolv.html> (12 April 2002).
This site concentrates on physical science examples in creative problem solving.

Teamworks Module: Problem-Solving. < http://www.vta.spcomm.uiuc.edu/PSG/psgl1-ov.html> (12 April 2002).
This site provides a four-lesson course in creative problem solving.

Object-Oriented Programming

Montlick, Terry. *What is Object-Oriented Software?* <http://www.catalog.com/softinfo/objects.html> (12 April 2002).
This site provides a student level online explanation of object oriented programming.

The following resources apply to specific teams:

Energy System Team (EST)

Arguments for Solar Energy. <http://www.solarenergy.org/> (16 April 2002).
This is an advocacy group for solar energy.

Building New Nuclear Power Plants. <http://www.nuclear-gen.com/press_old.htm> (12 April 2002).
This site links to new nuclear power plant technologies. Nuclear power is viable on Mars due to its high energy to mass ratio.

Concentrating Solar Power and Sun Lab. <http://www.eren.doe.gov/csp/> (16 April 2002).
This site is from the U.S. Department of Energy. It describes experiments in concentrating solar power.

Energy: Fuel Cells. 2002. <http://www.ecoworld.com/energy/EcoWorld_Energy_Fuel_Cells1.cfm> (16 April 2002).
This site provides access to articles on fuel cells

Environmental Health Programs: Division of Radiation Protection. 9 August 2002. <http://www.doh.wa.gov/EHP/RP/siemen2.htm> 12 April 2002.
This site describes the response to an emergency at a nuclear power plant.

Radiological Accidents. 15 October 1998. <http://virtual.clemson.edu/groups/ep/r_accid.htm> (14 April 2002).
This is another site that describes nuclear accidents and response strategies.

Natural Gas Fuel Cells. November 1995. <http://www.pnl.gov/fta/5_nat.htm> (16 April 2002).
This U.S. Department of Energy site provides descriptions of several types of fuel cell configurations

The Nuclear Advocate. <http://home.HiWAAY.net/~jeffj1/issues/nuclear/> (14 April 2002).
This article provides advocacy arguments for nuclear power.

Solar Electric Light Fund. < http://www.self.org/> (16 April 2002).
This is an advocacy group for solar power in underdeveloped regions.

Solar News. <http://www.solarpower.com/> (16 April 2002).
This site provides access to articles on solar power.

Water Exploration Team (WET)

Overview: The Quest for Water. <http://www.cnn.com/TECH/space/9911/29/lander.science/> (16 April 2002).
This CNN article describes a brief overview on the efforts to find available water on Mars.

Mars Researchers Spot Big Ice Deposit. 20 September 2000. <http://www.space.com/scienceastronomy/solarsystem/mars_ice_000920.html> (16 April 2002).
This article provides evidence of a huge underground water reservoir on Mars.

Report: Water springs found on Mars. <http://www.cnn.com/2000/TECH/space/06/21/mars.water/> (16 April 2002).
This CNN article describes the possible existence of water springs in a crater on Mars in the past. This could provide a possible colony site on Mars.

Plants For Settlers Team (PST)

Crop Physiology Laboratory - Research ALS: ADVANCED LIFE SUPPORT. <http://www.usu.edu/cpl/celss.html> (16 April 2002).
This article provides ideas about producing wheat in space. The advantages of bioregenerative and non-bioregenerative systems are discussed.

Mars Acadmey. <http://www.marsacademy.com/lss/lss12.htm> (16 April 2002).
This article introduces possible use of human wastewater in hydroponics gardening and the problems introduced. It is part of the course from the water and recycling team.

Fish for Food Team (FFT)

Fish Farming May Soon Overtake Cattle Ranching As A Food Source. <http://www.worldwatch.org/chairman/issue/001003.html>(16 April 2002).
This site offers an article on the growth of fish farming. The tons of fish from fish farms have more than doubled in the past decade while the amount of fish from our oceans and the amount of beef raised has leveled off.

Flowers Fish Farms: From Hobby to Profitable Business. <http://www.flowerscompanies.com/fishfarm.html> (16 April 2002).
This article gives an excellent description of a real fish farm. The farm primarily raises catfish.

Freshwater Fish Farming in Virginia: Selecting the Right Fish to Raise. April 1997. <http://www.ext.vt.edu/pubs/fisheries/420-010/420-010.html> (16 April 2002).
This article is an excellent source for determining the advantages and disadvantages of various types of fish as well as the conditions necessary to be successful at fish farming. Even though it is written for Virginia, it provides a good start for Mars.

Water Accumulation and Recycling Team (WART)

"Water on the Space Station." *Space Daily.* 2 April 2001. <http://www.spacer.com/news/iss-01p.html> (16 April 2002).
This article provides an introduction to the water recycling system planned for the space station. This article will justify the need for recycling in closed systems.

The sites below are part of an entire curriculum that describes life support for space and Mars. They are representative. Students need to begin here and go through all of the course and its links.

"The Closed Environment Life Support System." *Mars Academy.* <http://www.marsacademy.com/lifes3.htm> (16 April 2002).
(CELSS) is a NASA research project. It provides an excellent beginning of what will be required on Mars.

"Recycling Water." *Mars Academy.* < http://www.marsacademy.com/lss/lss7.htm> (16 April 2002).
This site raises the questions. The questions are addressed throughout the course.

"Waste management." *Mars Academy.* <*http://www.marsacademy.com/lss/lss13.htm*> (16 April 2002).
This article provides a brief introduction to waste management on Mars.

Manufacturing and Supplies Team (MAST)

Energy and Water Efficiency for Semiconductor Manufacturing. <http://www.pprc.org/pprc/pubs/topics/semicond/semicond.html> (16 April 2002).
This online source describes one need for ultra pure water, the semiconductor industry. Since Mars contains an ample amount of the materials used in semiconductors, it clearly is going to be a major manufacturing use of water on Mars. This article discusses all aspects of the cost of semiconductor manufacturing. The production and decontamination of water for the process is discussed thoroughly. One fact illustrates the dimensions of the problem: For every dollar spent on water coming into the plant, twenty dollars are spent on purifying and ten dollars on decontamination after use.