Initial Workshop Activity

You have just won a free shopping spree from your local pet store. You have 10 minutes to purchase items for a new marine aquarium. What will you buy?

• Use the ‘Marine Aquarium Shopping Spree’ questionnaire as needed. Keep this questionnaire to refer to at the end of the workshop.

Implementation Tips:
Completing the shopping spree first is important. This activity is intended to mimic what can happen on a project in real life. A business or family may make quick decisions about complex projects – due to perceived or real time constraints – only to result in a final product that is not acceptable and even more time and money is spent ‘fixing’ the product. The shopping spree activity allows the students to go through a similar experience only to find out – once they refer back to these purchase selections at the end of the lessons – that their informed choices, made after following a proven process, would have been very different. The goal is for the students to realize that the amount of effort to get to a better informed position was not too great or costly, and the small amount of effort put in at the beginning makes a huge difference in the end. This is the value of using systems thinking as part of a systems engineering process.
This workshop focuses on the use of a systems thinking approach as part of a systems engineering process to select a system concept for the design of a household or classroom marine (salt water) aquarium. The workshop addresses the needs of the users and maintainers of the aquarium over time, starting with developing the system concept and ending with retirement of the system, to enable the student to select an appropriate system concept for their aquarium design.

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Workshop Agenda

• Attendees:
  – Pick up supplemental activity sheets.
  – Presentation and Lesson Plan materials are available on the conference CD.
  – Complete roster (with e-mail, if follow-up desired).

• Schedule of Activities:
  – 10 minutes: Set-up and Intros: Shopping Spree
  – 20 minutes: Lesson One: The System Life Cycle
  – 20 minutes: Lesson Two: Stakeholders & Requirements
  – 30 minutes: Lesson Three: Choosing Your First Aquarium
  – 10 minutes: Wrap-up: Review of overall concepts, Q&A

For this complete lesson, the students begin with a mock activity where they are given a limited amount of time to choose the parts of their aquarium. Then the students go through the system engineering and system thinking steps for selecting a system concept. Stakeholders are identified and requirements are gathered using an interview process. Expert advice is included in the requirements gathering process. As the final step in the process, the Pugh matrix is used to select the first household aquarium. Students then compare the selected system concept chosen after applying systems engineering and systems thinking to their original aquarium selections. Students reflect on the differences before/after and lessons learned.
Workshop Objectives

By the end of the workshop, participants can:

• Describe the first three systems engineering steps and explain how we use systems thinking at each step to develop our system concept.
• Discuss the process of gathering stakeholder requirements and balancing multiple perspectives early in the system life cycle.
• Explain the Pugh Matrix based system concept selection process.
• Discuss the importance of considering cause/effect relationships in the final selection of the system concept.

These are the primary concepts that we hope you walk away with at the end of the workshop, and that your students walk away with when you go through this workshop with them.
These are the questions that will be asked at the end of the workshop. I want to present them here so that you have the opportunity to consider these questions as we are going through the workshop.

**Closing Questions**

These questions will be asked at the end of the workshop:

- List three things you learned from this overview of using system thinking as part of the systems engineering process to develop a system concept. What one idea do you think you will use the most often?
- If you could change one thing about this workshop, what would it be?
- Do you think you will use this lesson plan? Why or why not?
Definitions Used (p. 1 of 2)

- **System**: A system is a set of independent yet interrelated components working together to accomplish a common purpose – a purpose that could not be accomplished by the independent parts alone.

- **System Context**: The system context defines the boundary of the system, what is inside and what is outside the system, and how the system relates to its external environment.

- **Systems Thinking**: Systems thinking is critical thinking combined with a strong understanding of system concepts. Systems thinking related concepts we will cover include defining the system context, incorporating multiple perspectives, and understanding the impact of cause and effect relationships that can change the performance of our system.

These are important definitions used in the lessons and provided here for reference.

Here is the definition for critical thinking:

**Critical Thinking**: Critical thinking is also called high order thinking or disciplined thinking. We use critical thinking to process our thoughts, senses and feelings about the world around us. Critical thinking is used to question our understanding of the world in order to seek the truth.
Definitions Used (p. 2 of 2)

- **Stakeholder:** Stakeholders are those individuals involved in the design or use of a system; they have a vested interest in the system.

- **Systems Engineering:** Systems engineering is the process that we use to transform a need or opportunity into an operational system that meets the stakeholder requirements over the life of the system.

- **System Life Cycle:** The system life cycle is made up of phases that a system goes through from the system concept development phase until retirement.

- **Pugh Matrix:** A Pugh Matrix is a table that can be used to compare system concepts to stakeholder requirements.

Full definitions are:

**Stakeholder:** Stakeholders are those individuals involved in the design or use of a system; they have a vested interest in the system. Stakeholders are concerned about the system including what they want to use the system for, how much the system costs to make and use, where the system will be located, what they think is most important about the system, etc…

**System Life Cycle:** The system life cycle is made up of phases that a system goes through from the system concept development phase until retirement and/or replacement of the system.

**Pugh Matrix:** A Pugh Matrix is a table that can be used to compare system concepts to stakeholder requirements. In the Pugh Matrix, each concept is rated for whether it meets, does not meet, or exceeds each requirement.
Lesson One:
The System Life Cycle

Materials:
• Activity: Marine Aquarium Shopping Spree
• Presentation: The System Life Cycle

Procedure:
1. Students participate in Marine Aquarium Shopping Spree. Use the ‘Marine Aquarium Shopping Spree’ questionnaire as needed. This activity should be limited to 10 minutes.

2. Instructor provides an introduction for the lesson which should include an overview of all three steps of the systems engineering process and each concurrent step of systems thinking concepts that support exploring the system concept.

3. After the introduction, the instructor breaks the class into groups of 2 – 3 students to develop responses to the assessment questions.

4. Instructor leads a class discussion to review student responses to the assessment questions.
Lesson One Objectives

Students will be able to:

• Explain what a system is and give examples.
• Identify the phases of a system life cycle.
• Define systems engineering and systems thinking.
• List the systems engineering and systems thinking steps that support developing a system concept.

Lesson One: The System Life Cycle

These are the Lesson One Objectives. We will revisit these at the end of Lesson One.
What is a System?

• A system is a set of independent yet interrelated components working together to accomplish a common purpose.

• “The whole is greater than the sum of the parts.”

• Examples: Our Marine Aquarium
  – In Nature: ant colony, nervous system, coral reef
  – Man-made: car, satellite, computer, city

Before we talk about systems engineering, let’s first talk about systems. What is a system? You have heard the phrase “The whole is greater than the sum of the parts.” And that saying applies to many system. A system is a set of independent yet interrelated components working together to accomplish a common purpose – a purpose that could not be accomplished by the independent parts alone. When the system is organized properly, the system as a whole performs better than the sum of its parts. The marine aquarium is an example of a system.

Q: What are other examples of systems in nature?

Q: What are other examples of man-made systems?

Q: Is the World Wide Web (the internet) a system? Why or why not?

Q: Give an example of a system that does not follow the rule: “the whole is greater than the sum of its parts.”
Systems follow a system life cycle. Selecting the type of aquarium to design for the household or classroom is part of the ‘Develop System Concept’ phase. Once a viable concept is selected, various designs for that type of aquarium are investigated in the ‘Design System’ phase, and the final design chosen. The actual gathering of materials and setup of the marine aquarium is completed as part of the ‘Produce System’ phase. The aquarium water quality and ability to sustain life is tested in the ‘Test System’ phase. Once the aquarium is populated with the initial set of live inhabitants and has reached a stable sustainable environment, the aquarium has entered the ‘Sustain System’ phase. This can be a very long phase. When the aquarium is disassembled, that is the ‘Retire System’ phase.

Q: Your class is designing a classroom aquarium, what plans do you need to make to sustain the aquarium after the end of the school year?
What is Systems Engineering?

- Systems engineering is the process that we use to design a system that will achieve the desired system behavior over time.
- Stakeholders are involved in defining how the system should work. They have a vested interest in what the system can do.
- A successful system design balances the multiple perspectives and needs of the stakeholders.

If you are not sure what systems engineering is, you are not alone!

Q: Describe what systems engineering means to you, in your own words.

Systems engineering is a process that starts at the beginning of the system life cycle. The purpose of systems engineering is to make sure that we design a system that will work. The system was designed for a reason – the needs of the stakeholders. Stakeholders are those individuals involved in the design or use of the system. A successful system meets the needs of the stakeholders.

We will use this definition of systems engineering: “Systems engineering is the process that we use to transform a need or opportunity into an operational system that meets the stakeholder requirements over the life of the system.”
What is Systems Thinking?

- Critical thinking is used to examine and question the world around us. We use critical thinking to find the truth.
- Systems thinking is critical thinking combined with a strong understanding of system concepts.
- We use systems thinking when we perform systems engineering.

Systems thinking is critical thinking combined with a strong understanding of system concepts. What is critical thinking? Critical thinking is sometimes called higher order thinking or disciplined thinking. Critical thinking is more than just memorization or recalling facts. We use critical thinking when we question statements, integrate ideas, and evaluate alternatives. The idea of critical thinking is that of a watchful mind, always on alert – putting the inputs to the mind through an evaluation process. We use critical thinking to process our thoughts, senses and feelings about the world around us. Critical thinking is used to question our understanding of the world in order to seek the truth.

When you combine critical thinking with an understanding of systems and system concepts, you have systems thinking.

Systems thinking is the backbone of many systems related disciplines, including systems engineering.

Q: Give an example of how you might use systems thinking to solve a problem.
The systems engineering process starts with understanding the need or opportunity that the system is being designed for. In this case, there is a pre-existing need or opportunity for a classroom or household marine aquarium.

The next steps are identifying the stakeholders and gathering their requirements. Stakeholders are those who are involved in making our marine aquarium a success! Experts, those who know a lot about the system being designed, should also be part of the requirements gathering process. Requirements that span the life cycle of the system should also be included in the requirements gathering process.

The final step is defining and evaluating viable system concepts and selecting the system concept that we are going to design to.

These three steps apply to the design of a marine aquarium and provide an introduction to systems engineering. However, there are many more steps in the systems engineering process at each phase of the system life cycle.
When we define a need or an opportunity for a system, we need to understand the type of environment that the system will have to operate in. We have to bound the system. We need to understand what the system will do, and what it will not do; we need to understand what parts of the environment belong in the system and what parts of the environment will be outside of our system. The system boundary and the type of environment the system will operate in form what we call the system context. We use systems thinking to understand the system context and this helps us to better define the need or opportunity for our system.
Another aspect of systems thinking that comes into play when gathering our stakeholder requirements is the ability to understand multiple perspectives. Our stakeholders will each have varying backgrounds, different personalities and goals, and they will have different requirements for our system. Sometimes the requirements of the stakeholders will be directly opposing. Understanding multiple perspectives can help us make it through this step of the systems engineering process. We will want to be able to find ways to satisfy all the stakeholders so that we will be able to build our marine aquarium.
We will also need to understand multiple perspectives for identifying all of the possible system concepts that we can use for designing our system. In order to define, evaluate and select a proper system concept from the set of concepts identified, we will need to understand the cause and effect relationships that apply to our system or to each system concept. For example, the location of our aquarium (direct sun, indirect sun, shade) and the temperature of the surrounding air can affect the temperature of the water in our aquarium. As the external temperature rises, the internal temperature rises, and vice versa. We will need a way to keep the temperature of our water at the right level to keep the aquarium inhabitants alive.
Lesson One Objectives

Students will be able to:
• Explain what a system is and give examples.
• Identify the phases of a system life cycle.
• Define systems engineering and systems thinking.
• List the systems engineering and systems thinking steps that support developing a system concept.

Lesson One: The System Life Cycle

Did we meet the objectives?
Ask the audience to respond to each objective.
Lesson Two: Identifying Stakeholders and Gathering Requirements

Materials:
- Lesson Two: Identifying Stakeholders and Gathering Requirements
- Take Home or In class Activity: Requirements Survey

Procedure:
1. Instructor provides an introduction for the lesson which should include an overview of identifying stakeholders, a discussion of the importance of incorporating multiple perspectives, and the process of gathering a broad set of requirements.
2. Instructor reviews the ‘Requirements Survey’.
3. After the introduction, the instructor breaks the class into groups of 2 – 3 students to develop responses to the assessment questions listed below.
4. Instructor leads a class discussion to review student responses to the assessment questions.
5. Students gather requirements for their aquarium using the Requirements Survey as a starting point. This can be accomplished by either forming groups in class and having each member play a stakeholder role, or as a homework assignment where family members or other stakeholders are interviewed.
Lesson Two Objectives

Students will be able to:

• Explain what a stakeholder is and list examples of stakeholders.
• Describe a general process for collecting stakeholder requirements.
• Discuss the importance of balancing multiple perspectives.
• Explain the role of expert advice in selecting the right system concept.

Lesson Two: Identifying Stakeholders and Gathering Requirements

These are the Lesson Two Objectives. We will revisit these at the end of Lesson Two.
What is a Stakeholder?

- Stakeholders are those individuals involved in the design or use of the system.
- Here are some questions you can ask to determine who your stakeholders are:
  - Who is paying for the aquarium?
  - Who is the aquarium for?
  - Who will maintain the aquarium?
  - Who provides parts for the aquarium?
  - Who provides expert information about the aquarium?
  - Who is designing the aquarium?
  - Who establishes rules or guidelines for the aquarium?
  - Who will use or view the aquarium?
- Don’t forget, you are a stakeholder too!

(Payee) Someone needs to pay for the aquarium!
(Customer/Owner) The person for whom the system is being designed, is the customer. The customer is usually the person that owns the system once it is complete.
(Maintainer) Daily and weekly maintenance activities must be completed to keep a ‘well maintained’ aquarium.
(Parts Provider) Manufacturers who make the products you use
(Expert/Trainer) The pet store employees, authors, relatives
(Designer) A team that includes you.
(Legal/Standards Body) Parent – special rules.
(User) The users of the system will decide whether the system is a success or failure.

Q: Make a list of stakeholders for the aquarium, by name. Who is the most important stakeholder for your salt water aquarium? Why?
Q: Are the fish and other living sea creatures in your marine tank stakeholders? Why or why not?
Stakeholder Requirements

• Main Challenges:
  – Gathering a complete set of requirements
    • Missing or late requirements may force a redesign.
    • A full set of requirements is needed to get a complete perspective.
  – Balancing Multiple Perspectives
    • Some requirements may appear to be directly opposing.
    • Dig deep to understand what the stakeholders really want.

Once the stakeholders are identified, the next step is to collect the stakeholder requirements. One challenge in collecting stakeholder requirements is that many times stakeholders do not realize all of their requirements until they see the system in action. However, once the aquarium is set up and running, it is too late to find out that your stakeholder has a requirement that you can no longer meet! When it comes to setting up a marine aquarium, a redesign can prove timely, costly, and sometimes impossible. Therefore you need to make sure you gather a complete set of requirements. Another challenge is that stakeholders do not always appear to agree on the requirements for the system. One important aspect of systems thinking is the ability to incorporate multiple perspectives. When stakeholders do not agree we need to dig deeper to understand their true requirements which will help us balance the multiple perspectives.
Gathering a Complete Set

• Collect requirements through interviews
  – Prepare a set of starter questions
  – Listen to and write down requirements!
  – Add new questions to starter set through the interview process
• Include stakeholders across each area of the system life cycle
• Include requirements across broad areas, not just cost, or aesthetics (looks)

There are methods you can use to help your stakeholders think about all of their requirements. One method is to interview your stakeholders. Before you interview your stakeholders you should prepare a set of questions to ask them about the marine aquarium. These questions should take into account all the many types of stakeholders that are interested in your system. These questions should span many different areas that must be considered before designing your aquarium.

Your job is to write down these requirements so that you don’t forget them! You will need them later.

Q: Add 3 new questions to your requirements survey that will help you collect stakeholder requirements.

Q: What else can you do to make sure you are not missing requirements?
Balancing Multiple Perspectives

• Help stakeholders visualize aquarium
  – Show sample pictures of aquariums
  – Talk about what it will be like to have an aquarium

• Share information and ideas
  – Educate stakeholders about the system
  – Help stakeholders see other perspectives

• Dig deeper
  – Use the Five ‘Whys’ technique

During the interview, in order to better understand your stakeholder’s perspective, talk to your stakeholders about different types of marine aquariums, show them pictures of what various aquariums might look like, talk about how the aquarium will be set up and maintained, and share other ideas you have for your marine aquarium. The questions and information you provide will help your stakeholders visualize the marine aquarium when it’s in operation, and that visualization will help the stakeholder to communicate their requirements more accurately.

However, the main way to understand your stakeholder’s perspective is to listen. Sometimes, especially if you have opposing requirements, you need to dig deeper. Asking ‘why’ up to five times can help you get a better understanding of your stakeholder’s requirements so that you can balance the multiple perspectives from the many stakeholders and come up with a good solution.

Q: How are gathering a set of complete requirements and balancing multiple perspectives related?
Stakeholder requirements are typically grouped into categories, examples include:

- Cost
- Time or Schedule
- Environmental Impact
- Aesthetics (looks)
- Performance
- Location
- Maintenance / Sustaining Operation

Examples of requirements in each category:

**General**: “The aquarium shall have the soft soothing sound of falling water at all times.”

**Cost**: “The aquarium shall cost no more than twice the amount of our current freshwater aquarium.”

**Environmental Impact**: “The aquarium shall only have inhabitants that were bred in captivity.”

**Time**: “The aquarium shall take no more than one day to set up.”

**Aesthetics (looks)**: “The aquarium shall look really cool.”

**Performance**: “The aquarium shall make me feel happy.”

**Location**: “The aquarium shall be at eye level when I sit down.”

**Maintenance**: “The aquarium shall be relatively easy to maintain.”

What are your top 3 requirements for your marine aquarium? Use the questions on the requirements survey to give you some ideas.
Before you conduct your stakeholder interviews, you should be knowledgeable about the system that you are designing. Requirements should also be collected from experts and through research. A successful marine aquarium requires an in-depth understanding of the requirements of the marine environment and the creatures that live there. Be sure to review the Marine Aquarium Facts (next pages). You can also check out and read books from your school or local library on marine aquariums or marine fish. The World Wide Web (internet) is a good place to find free information on marine aquariums. Be sure to avoid online ads and make sure you use ‘safe’ websites as you would whenever you use the internet.

Q: Name 3 sources of expert information you can use to research information on your aquarium.
Marine Aquarium Facts

• The compatibility of the marine life in the aquarium is the single most important consideration – since there is only one environment.

• Water quality is the most important factor for keeping the aquarium inhabitants alive.
  – Aquariums must initially cycle through high levels of:
    • First Ammonia
    • Then Nitrite
    • And finally, nitrate
  This is called ‘cycling’ the aquarium.

• Salt water friendly equals salt water safe!

Compatibility: lighting, water quality, aggressiveness/diet.

Water quality: ammonia, nitrite and nitrate and the pH level; temperature and salinity of the water.

Before you can add many fish, the aquarium must first ‘cycle’ through high levels of ammonia, then nitrite, both of which are harmful to the fish, and then finally nitrate which is not harmful to the fish.

Salt water friendly equals salt water safe! Careful of substances that can leach dangerous chemicals into the salt water. Do not include items that contain metal. Sterilize.
More Marine Aquarium Facts

• The amount of fish in the water has a direct effect on the water quality.
  – Freshwater: 1 inch (length) of fish per gallon of freshwater
  – Fish-only Marine: 1 inch of fish per three gallons of salt water
  – Mixed (corals with some fish): 1 inch of fish per five gallons of salt water

• The amount of natural lighting, weight bearing capacity and external temperature fluctuation are important considerations when choosing a location for the aquarium.
  – To calculate weight: 8.5 pounds per gallon of sea water, plus additional weight of tank, results in the rule of thumb of 10 pounds per gallon of water.

More fish means more excess food and more waste. Beginners may want to cut in half! Freshwater: 1 inch/gallon, Fish-only: 1 inch /3 gallons, Mixed: 1 inch / 5 gallons

Location: natural lighting, weight bearing, temperature fluctuation. 10 pounds per gallon of water rule of thumb.
Activity:
Gathering Requirements

- Form into groups.
- Each group member assumes a particular role in the household – mom, dad, brother, sister, grandparent, etc...
- Take turns interviewing each other to gather the stakeholder requirements.
- Focus on the ‘top’ 3 requirements per person.
- Gather at least 5 ‘top’ requirements, including your own requirements.

Implementation Tip:
As an alternative to taking the requirements surveys home, the class can form into groups and each group member can take on a particular role in the household – mom, dad, brother, sister, grandparent, etc… Then the group members can take turns interviewing each other to gather the stakeholder requirements. It’s important to focus on only the top 2 to 3 requirements for each stakeholder. The more stakeholders there are, the less ‘top’ requirements that should be collected from each one so that the students end up with between 5 to 12 ‘top’ requirements, including their own.

My top 3: I don’t have to do anything, there is no damage to my house, and the aquarium looks cool. 😊
Lesson Two Objectives

Students will be able to:

- Explain what a stakeholder is and list examples of stakeholders.
- Describe a general process for collecting stakeholder requirements.
- Discuss the importance of balancing multiple perspectives.
- Explain the role of expert advice in selecting the right system concept.

Lesson Two: Identifying Stakeholders and Gathering Requirements

Did we meet the objectives?

Ask the audience to respond to each objective.
Lesson Three: Choosing Your First Aquarium

Materials:
Presentation: Choosing Your First Aquarium
Worksheet: Completing the Pugh Matrix

Procedure:
1. Instructor provides an introduction for the lesson which should include an overview of how to apply the Pugh matrix to select a system concept for the aquarium and a discussion of cause/effect relationships.
2. Complete the “Choosing your First Aquarium” handout.
3. The instructor breaks the class into groups of 2 – 3 students to develop responses to the assessment questions.
4. Instructor leads a class discussion to review student responses to the assessment questions.
5. Instructor leads discussion with students on the differences between the original selections of the aquarium, and the final system concept selected. Students discuss the lessons they learned from the experience.
Lesson Three Objectives

Students will be able to:

• Explain what a Pugh matrix is and how it can be used.
• Complete a system concept selection process using the Pugh matrix.
• Discuss the cause/effect relationships that impacted the system concept selection process.

Lesson Three: Choosing Your First Aquarium

Objectives:

These are the Lesson Three Objectives. We will revisit these at the end of Lesson Three.
The Pugh Matrix

• We will use a Pugh matrix to guide the aquarium selection process.
  – The Pugh matrix will be used to organize information to make an informed decision.
  – The Pugh matrix is used very early in the concept selection process.
    • To choose from alternatives or concepts.
    • Not much detail yet known or available.
  – The concepts being evaluated are separated from the requirements used to select them.
    • Concepts are listed across the top row.
    • Requirements are listed down the left column.

Once the aquarium research is complete and the requirements are collected from the stakeholders, you will select what type of aquarium to start with. To assist with the selection process you can use the Pugh matrix. The matrix is a table used to organize the information for making an informed decision. Stuart Pugh introduced this matrix in 1991 as a way to help compare alternatives when there is not a lot of detailed information. The Pugh matrix separates the alternatives from the criteria. We will be using requirements as the criteria to select between the alternatives for our aquarium.

The first column of the Pugh matrix is used to list the criteria or requirements, one requirement for each row of the table. The rest of the columns are used to gather information for each alternative or concept, with each column representing a different concept.
This is what a Pugh matrix looks like.

Concepts are listed along the top row and requirements are listed down the first column. The totals for each rating:

‘+’ for better than requirement
‘S’ for meets the requirement
‘-’ for does not meet the requirement

Are listed in the last three rows of the table.
Populating the Pugh Matrix

- List concepts across the top row of a table.
- List the requirements down the left hand side of a table.
- Populate the table. Label each concept as follows for each requirement:
  - ‘+’ means that the concept more than meets the requirement (is better than what is required).
  - ‘S’ means that the concept meets the requirement.
  - ‘-’ means that the concept does not meet the requirement.
- Count the number of ‘+’, ‘S’, and ‘-’ for each concept and write the sums in the bottom three rows of the table.

To populate the Pugh matrix start by listing the alternatives – in our case our system concepts – along the top row of the table, skipping the first column. Next write the criteria – in our case our requirements – down the first column, one requirement per row. Next, decide whether each alternative is better than the requirement (+), meets the requirement (S) or does not meet the requirement (-). Once you are done, count the number of each, for each concept, and write the sums down in the last three rows of the table.
Selecting your Concept

• Use the sums to guide the process.
  – Let the totals for each concept guide decisions, do not allow totals to make the decision for you.
  – For example, just because one concept has the most ‘+’s does not mean that is the concept to select.
  – You are the best judge of the right concept to select. The table simply offers a method for viewing and summarizing the information.
  – Allow the matrix to ‘inform’ but not to ‘determine’ the answer.

Q: Provide an example where using the Pugh matrix could help you make a decision. List three or more different alternatives or concepts you might select from.

When using the Pugh matrix, you could always choose the concept with the least number of ‘-‘s (does not meet the requirement). Is it a good idea to use a rule such as this for making your final selection using the Pugh matrix? Why or why not?
Example: Selecting a Pet

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Dog</th>
<th>Cat</th>
<th>Snake</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can take for a walk</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Provides companionship</td>
<td>+</td>
<td>S</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Can leave home alone for long periods of time</td>
<td>-</td>
<td>S</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Can take for a car ride</td>
<td>+</td>
<td>S</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Easy to take care of</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>+</td>
</tr>
<tr>
<td><strong>Total +</strong></td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total S</strong></td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Use ‘+’ for better than requirement  
Use ‘S’ for meets the requirement  
Use ‘-’ for does not meet the requirement

As an example, let’s look at the how we might use the Pugh matrix to help us decide on what type of pet might best fit our requirements. As shown, based on our requirements, we find that the dog exceeds on three requirements, but does not meet two requirements. The cat does not exceed requirements in any area, but meets 4 out of the 5 requirements. Yet the snake and the fish can be left home alone for long periods, much longer than the amount of time we might be able to leave a dog home without disastrous consequences (to the dog or to our house!). However, the snake does not meet three requirements. The fish are enjoyable to watch and comparatively easy to take care of but do not meet 3 out of 5 requirements. Which one would you choose?

Q: What are your top three requirements for a pet?  
Q: What pets would you include in the selection process?
Which Pet?

Using the Pugh Matrix as a guide:

- Michael chose the dog, as a dog offers the best match to his requirements and he will make sure not to leave the dog home alone for long periods of time.
- Joshua chose the fish as he has to be able to leave his pet home alone for long periods of time and most of all he wants something he will enjoy watching.
- Justin chose the cat because he only wants some companionship, not too much, and he wants the flexibility to take his pet with him or leave the pet at home.

Here are some example choices using the previous Pugh Matrix as a guide to select a pet,

Notice that to Michael, Joshua and Justin, certain requirements are more important than other requirements and this level of importance influences their final choice.
Cause/Effect Relationships

- All pets require a time commitment
  - Potty training
  - Behavioral training
  - Companionship
  - Daily feeding
    - Some pets require to be fed live food.
    - Clean, Safe Environment
- Household members may be allergic to certain pets or pet products or pet food.
- A pet’s behavior can become unsafe to others under certain circumstances.

Cause/effect relationships can impact only the system, or they can affect the environment in which the system resides.

For our Pet Selection exercise, many cause/effect relationships exist. Some are listed here. For example, in every case a pet requires a time commitment on the part of its owner or caretaker. Some pets need to be potty trained if they are to be part of the household. Others need behavioral training in order to act appropriately around people. Some pets require companionship while others want to be left alone. Most pets require some type of daily feeding and a clean, safe environment in which to live.

Other cause/effect relationships that should be considered are household or classroom members may be allergic to certain pets or products put on the pets or even the food used to nourish the pets. And pets are wild animals and can behave in an unsafe manner under certain circumstances.

Ultimately, an understanding of cause/effect relationships will aid in the final selection of a system concept.
Using the Pugh Matrix to Select the First Aquarium Type

• We will use the Pugh matrix to select an aquarium based on the available requirements.
• The aquarium choices for this activity will be:
  – Marine Fish-Only
  – Marine Mini-Reef/Corals
  – Marine Mixed (Fish and Corals)
  – Freshwater

The aquarium choices for this activity will be:
• Marine Fish-Only: Contains only fish.
• Marine Mini-Reef/Corals: Contains hard and soft corals, sponges, anemones and other types of sessile (non-moving) invertebrates (no backbone). This type of aquarium does not typically contain fish of any kind.
• Marine Mixed (Fish and Mini-Reef): A mixed aquarium is a mini-reef/corals aquarium that has fish!
• Freshwater: This is the easiest aquarium to start with and guarantees the best chance for success.
Marine Fish-Only: Contains only fish. Examples include: a) a community of compatible marine fish with similar environmental needs that all get along, or b) a single specimen that is better kept alone because it is large and aggressive or predatory. This type of aquarium may optionally contain benign crustaceans (like shrimp or crabs) and/or benign Mollusks (like clams or oysters). This aquarium may not have the look that you are trying to achieve.
Concept Two:
Marine Mini-reef/Corals

- A Mini-reef/Corals aquarium may include:
  - Hard corals
  - Soft corals
  - Sponges
  - Anemones
  - Other types of sessile invertebrates (non-moving sea creatures with no backbone)
  - Typically, no fish!
- Requires:
  - Intense lighting
  - Better water quality
  - Is more effort to maintain than fish only or freshwater
- Does not have the marine ecosystem ‘look’.
  - Little to no live moving sea creatures
  - Pretty, but may be considered boring

Marine Mini-REEF/Corals: Contains hard and soft corals, sponges, anemones and other types of sessile (non-moving) invertebrates (no backbone). This type of aquarium does not typically contain fish of any kind. The mini-reef requires intense lighting to keep the sea life alive. This aquarium may not have the look that you are trying to achieve.
Marine Mixed (Fish and Mini-reef): A mixed aquarium is a mini-reef/corals aquarium that has fish! In its simplest version the fish do not feed on the coral. This aquarium has the most likeness to a marine ecosystem and setups can range from simple to very complex. The mixed aquarium is the most difficult to maintain because the water quality and temperatures as well as lighting must be kept at very specific levels. There is more chance of failure of this type of complex marine ecosystem, including unexplained mortality and missing sea creatures.
Concept Four: Freshwater

- A freshwater aquarium does not require salt water
  - The more common type of aquarium
  - Fish are more readily available
  - Equipment is more readily available
  - More choices in many areas
- Compared to a marine aquarium, a freshwater aquarium and its inhabitants:
  - Are generally less expensive
  - Are generally easier to maintain
  - More fish per gallon of water
  - Overall the aquarium has a better chance of success
- May not have the look that you are trying to achieve
- May lose interest

Freshwater: This is the easiest aquarium to start with and guarantees the best chance for success. However, many aquarium enthusiasts start with a marine aquarium after they have done their research. Since the freshwater aquarium is the more common type of household aquarium, there is better availability of both inhabitants and equipment. Fish are generally less expensive and the aquarium itself is generally easier to maintain. Also, you can have more fish per gallon of water in a freshwater aquarium. On the other hand, the aquarium may not have the look you are trying to achieve and you may lose interest.
Activity:
Choosing your First Aquarium

- Read through the aquarium type definitions.
- List the top 5 to 12 stakeholder requirements down the left hand side of the Pugh matrix provided.
- Analyze each concept (add your own, if desired) against each requirement and fill in the ratings:
  - Use ‘+’ for exceeds requirement
  - Use ‘S’ for meets the requirement
  - Use ‘-’ for does not meet the requirement
- Sum the numbers for each concept.
- Which concept did you choose, and why?
- What cause/effect relationships did you consider?

Complete this activity using the ‘Choosing your First Aquarium’ worksheet.

For the aquarium type selected, list some of the requirements you will need to meet in order to insure you have a well maintained aquarium.
Pugh Matrix Afterward

• Use the same process with more detailed system concepts in any one area for your first aquarium.

• The concepts or alternatives should be well defined before applying the Pugh matrix process.

• When using the Pugh matrix you cannot choose a concept that you do not consider, so be sure to include a broad range of concepts.

It is not unusual to repeat the process to add new choices based on combinations of the original choices or new ideas, to include new requirements not previously considered or thought of, or to change ratings based on new information.

Whenever defining concepts for the Pugh matrix, they should be well defined before applying the Pugh matrix process. It is important to use a broad set of concepts to choose from.

What if you cannot decide between two types of aquariums? If time and money allow, two concepts can be carried forward. You could have one type of aquarium that you also use as a quarantine tank – to introduce new fish or put sick fish for treatment, for example – and a second main aquarium.
Lesson Three Objectives

Students will be able to:
• Explain what a Pugh matrix is and how it can be used.
• Complete the concept selection process using the Pugh matrix.
• Discuss the cause/effect relationships that impacted the system concept selection process.

Lesson Three: Choosing Your First Aquarium
Objectives:
Did we meet the objectives?
Ask the audience to respond to each objective.
Workshop Summary

These lessons can be further adapted to the design of a classroom marine aquarium.

The class could plan for and build an aquarium in the classroom, making sure to plan what will happen to the aquarium and its inhabitants at the end of the school year. Many lessons can be tailored around the ‘closed’ marine aquarium ecosystem and students can be directly involved in the care of the marine aquarium.

Challenge topics: Breeding in the Marine Tank, Diagnosing Ailments, Photographing Fish, How Biological Filtration Works, Venomous Fish and other Sea Creatures, Conservation of the World’s Coral Reefs, The Marine Aquarium and Stress Relief, The Impact of the Marine Aquarium on the Ecosystem
Post Workshop Activity

• Using your newly selected system concept, how would your selections for the ‘Marine Aquarium Shopping Spree’ change? Compare your selections now to those at the beginning of the workshop. What’s different? Why?

You have just won a free shopping spree from your local pet store. You have 10 minutes to purchase items for a new marine aquarium. What will you buy?

Alternatively: Now that you have selected your first marine aquarium, go back and review your shopping spree purchases. What items can you keep? What items do you need to return? Why?
Workshop Objectives

By the end of the workshop, participants can:

- Describe the first three systems engineering steps and explain how we use systems thinking at each step to develop our system concept.
- Discuss the process of gathering stakeholder requirements and balancing multiple perspectives early in the system life cycle.
- Explain the Pugh Matrix based system concept selection process.
- Discuss the importance of considering cause/effect relationships in the final selection of the system concept.

Did we meet our objectives?

Ask the audience to respond to each objective.
Wrap-Up

• List three things you learned from your introduction to systems engineering. What one idea do you think you will use the most often?
• If you could change one thing about this workshop, what would it be?
• Do you think you will use this lesson plan? Why or why not?

What questions do you still have?

Discuss:

• List three things you learned from your introduction to systems engineering. What one idea do you think you will use the most often?
• If you could change one thing about this workshop, what would it be?
• Do you think you will use this lesson plan? Why or why not?
Thank You!

Questions?

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This workshop reviews systems engineering principles using the design of a household marine (salt water) aquarium. The workshop addresses the needs of the users and maintainers of the aquarium starting with exploring the system concept and ending with retirement of the system.