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.
System Concepts and the Design of a Household or Classroom Marine Aquarium

Alice Squires: asquires@stevens.edu

Stevens Institute of Technology, School of Systems and Enterprises
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
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.
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.
• **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.
Lesson One:
The System Life Cycle
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.
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
The System Life Cycle

- Develop System Concept
- Design System
- Produce System
- Test System
- Sustain System
- Retire/Replace System

The System Life Cycle

Develop System Concept → Design System → Produce System → Test System → Sustain System → Retire/Replace System → Develop System Concept
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.
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.
Identify a Need or Opportunity
Identify Stakeholders and Gather Requirements
Define, Evaluate and Select System Concept
Systems Thinking
Develop System Concept

Identify a Need or Opportunity

Understand the System Context and Define the System Boundary

Classroom or Household Marine Aquarium
Systems Thinking
Develop System Concept

1. Identify a Need or Opportunity
2. Understand the System Context and Define the System Boundary
3. Identify Stakeholders and Gather Requirements
4. Incorporate Multiple Perspectives, both People and System Views
5. Classroom or Household
   - Marine Aquarium
   - Parents, Teachers, Aquarium Experts, Other family or class members
Systems Thinking
Develop System Concept

Identify a Need or Opportunity

Understand the System Context and Define the System Boundary

Define, Evaluate and Select System Concept

Incorporate Multiple Perspectives, both People and System Views

Classroom or Household Marine Aquarium

Parents, Teachers, Aquarium Experts, Other family or class members

Recognize and Understand Cause/Effect Relationships

Identify Stakeholders and Gather Requirements
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 Two: Identifying Stakeholders and Gathering Requirements
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.
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!
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.
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)
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
Requirements Survey

• Stakeholder requirements are typically grouped into categories, examples include:
  – Cost
  – Time or Schedule
  – Environmental Impact
  – Aesthetics (looks)
  – Performance
  – Location
  – Maintenance / Sustaining Operation
Ask the Expert

• A Successful Aquarium Requires:
  – Compatible fish and inhabitants
  – One environment
    • Certain amount of light and intensity
    • Specific level of Salinity (salt level)
    • Consistent Temperature Range
    • Livable Ammonia, Nitrite, Nitrate levels

• Learn about your aquarium
  – Talk to experts
  – Research: school, library, Internet
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!
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.
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.
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 Three:
Choosing Your First Aquarium
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.
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.
<table>
<thead>
<tr>
<th>Requirement 1</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement 2</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>S</td>
</tr>
<tr>
<td>Requirement 3</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Requirement 4</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Requirement 5</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Total +</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Total S</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total -</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Use `+` for better than requirement
Use `S` for meets the requirement
Use `-` for does not meet the requirement
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.
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.
## Example: Selecting a Pet

<table>
<thead>
<tr>
<th></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</td>
<td>-</td>
<td>S</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>periods of time</td>
<td></td>
<td></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>Total +</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total S</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total -</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Use ‘+’ for better than requirement
Use ‘S’ for meets the requirement
Use ‘-’ for does not meet the requirement
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.
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.
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
Concept One: Marine Fish Only

- Examples include:
  - A community of compatible marine fish
    - Similar environmental needs
    - They all get along!
  - A single specimen that is better kept alone.
    - Large
    - Aggressive or predatory

- Can contain:
  - Benign crustaceans (like shrimp or crabs)
  - Benign Mollusks (like clams or oysters)

- Does not have the marine ecosystem ‘look’.
  - No coral, sponges or anemones
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
Concept Three: Marine Mixed

- A mixed aquarium is a mini-reef/corals aquarium that has fish!
  - In the simplest version, fish do not feed on the coral
  - Has the look of a marine ecosystem
  - Can range from a simple to a very complex ecosystem
- Most difficult to maintain
  - Water quality must be closely monitored
  - Many maintenance activities more often
- The different lighting needs of the inhabitants needs to be addressed.
- More chance of failure of the ecosystem
  - Unexplained mortality
  - Disappearing 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
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?
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.
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.
Workshop Summary
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?
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.
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?
Thank You!

Questions?

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