Competency-Based Engineering Design Projects

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ABSTRACT

An outcomes-based approach to education is becoming essential for engineering educators. Design competencies help one define educational outcomes, develop plans for achieving integrated design experience, and document educational program success. The authors present a set of eight categories of design competencies to be used as a basis for structuring effective engineering design projects. During project development, the eight categories of competence are checked against anticipated steps in the project to assess the structure of the project and to direct modifications that will more fully achieve desired design education outcomes. An example is included to assist faculty in adoption of a competency-based approach to project development. This approach provides a basis for outcomes-based design education, even when students transfer from one program or institution to another.

KEYWORDS

Engineering design education, learning outcomes, curriculum design, collaborative learning

INTRODUCTION

Changes in Engineering Education

In recent years, concerns about engineering education in the United States have risen from a number of different sectors. Industry calls for restructuring engineering education to prepare graduates for a more competitive environment, and companies are willing to participate in this restructuring (Black, 1994). Katz (1993) indicates that engineers entering the workforce need skills in communication and teamwork, frequently lacking in their preparation. Input from a variety of sources, including industry and educators, indicates that selected design-related skills (e.g., problem definition, communication, teamwork) are more important for graduating engineers than some technical skills (Evans et al., 1993).

Many engineering educators are responding to calls for improved social awareness and communication skills through writing-across-the curriculum and design initiatives (Ludlow and Schulz, 1994; Gorman et al., 1995; Fentiman and Demel, 1995; Vest et al., 1995). Davis et al.

(1993) developed a design core that include social issues and communications in the freshman through senior years of the engineering curriculum. Calkins et al. (1995) integrated communications into a freshman design course used as part of the ECSEL coalition. In many cases, design has been used as a central element of engineering education reform, with its associated inclusion of teamwork and social issues (Quinn, 1994; Wilczynski and Douglas, 1995; Harris and Jacobs, 1995; Dally and Zhang, 1993).

A number of engineering educators have investigated issues that affect students' learning and how interactive group learning methods benefit students with a variety of learning styles (Eder, 1994; Montgomery and Fogler, 1996; Scrivener et al., 1994; Lumsdaine and Lumsdaine, 1995; Howell (1996); Ko and Hayes; 1994; Catalano, 1994; Byrd and Hudgins, 1995). They identify benefits from using team-based projects and suggest ways to structure, group, manage, and evaluate teams.

Focus on Competencies

A restructuring of engineering education requires clear definition of the educational outcomes expected at the end of a baccalaureate engineering degree. In the case of the design component of curricula, these outcomes define what the student has learned and is capable of doing with respect to design. The set of outcomes which apply to all of the engineering disciplines become criteria for the curricula. Achievement of these outcomes requires assessment at critical points in the educational process if growth in student design ability is to be developed throughout the curriculum.

This perspective is reflected in proposed changes in accreditation requirements set by the Accreditation Board for Engineering and Technology (ABET, 1995). These criteria place responsibility on the institution to define program outcomes, describe how they are being achieved, and produce evidence that they are being achieved. Thus, engineering educators must understand concepts of educational outcomes and aim their reform efforts at achieving these outcomes.

Few engineering educators have addressed the issue of measurable engineering outcomes. Montgomery and Fogler (1996) review instructional software with respect to its ability to teach desired engineering competencies—such as presentation of information, assessment of knowledge, exploration of topics, and analysis of concepts. Competencies have been used as the basis for structuring learning activities for development of engineering design outcomes in the first two years of engineering curricula (Crain et al., 1995). This work is part of the TIDEE project described below.

The "Transferable Integrated Design Engineering Education" (TIDEE) project, funded by the Course and Curriculum Development and the Undergraduate Faculty Enhancement programs of the National Science Foundation, is a collaborative effort among Washington State University, University of Washington, and Tacoma Community College with active participation from over 25 institutions in the state. The overall goal of this project is to structure undergraduate engineering design education during the first two years to produce flexible yet consistent engineering design preparation for a diverse pool of students following a variety of paths toward their degrees.

Implementation of the TIDEE project has engaged faculty throughout the state of Washington in discussions of engineering design, basic design competencies needed by students at various stages in their education, and strategies for achieving competence. The project leaders have employed collaborative learning successfully in activities with faculty, undergraduate students, and pre-college students, and they have focused activities in each case on increasing participants' understanding of competencies and enhancing their achievement of design competencies.

Although specific competencies defined for the first two years are not relevant to this paper, the categories of design competencies are useful for development of curricula and specific instructional materials. In the following sections, we describe categories of design competencies and then illustrate how these categories are used to create engineering design projects that achieve the desired design competencies.

CATEGORIES OF DESIGN COMPETENCE

Engineering design competencies can provide the basis for structuring engineering design education to offer students educational flexibility while also ensuring achievement of curricular objectives. Eight categories of design competencies are defined to encompass the skills and knowledge essential for engineering design. These categories of competencies are employed repeatedly throughout the development and implementation of a design solution. Their achievement is essential to preparing graduates for engineering practice; thus, they serve as educational objectives for both curriculum design and outcomes assessment.

Definitions of the eight categories of competencies are given below with examples of specific measurable competencies to help clarify each category. These specific competencies are generic enough to apply to all engineering disciplines and from freshman to graduating senior. Additional competencies may be added under these categories to complete the set for a given discipline.

Communication

Engineers must be able to communicate effectively at all stages of development and implementation of a design. This includes skill in listening and speaking to others individually, in groups or teams, and in public formal or informal presentations. They must be able to obtain information from direct observations or others' reported observations and capture it accurately, for example, in a design journal. Engineers must be able to communicate using sketches, technical drawings, graphs, charts (e.g., flow, organizational, control), photographs, and other visual aids. They must demonstrate writing proficiency in forms such as technical reports, memos, fabrication or user instructions, and nontechnical communications. They must be familiar with electronic technology and software used for these types of communications.

Examples of measurable COMMUNICATION outcomes are:

- Grasp important information accurately from verbal conversations or presentations
- Communicate information and concepts orally in language, enunciation, and organization that are easily understood
- Demonstrate nonverbal mannerisms that facilitate communication
- Give and receive criticism that produces improvement

- Record activities, observations, ideas, data, and interpretations faithfully in a personal design journal
- Present design information effectively in group oral presentations
- Present technical information accurately and clearly using appropriate format for formal or informal reports
- Prepare memos that communicate information clearly and professionally
- Communicate relationships accurately through use of appropriate drawings, sketches, diagrams, or other visuals
- Demonstrate competence with electronic mail, text processing, CAD and other graphics software used in engineering communication

Teamwork

Engineers must be able to work effectively in informal groups or structured teams. This requires their understanding of roles and management needed for teamwork as well as their being able to perform well as part of an effective team. Engineering design teams should capitalize on the diverse perspectives and skills of team members, producing better results collectively than they could do individually. Specifically, teams must demonstrate proficiency in the tasks associated with the engineering design process.

Examples of measurable TEAMWORK outcomes are:

- Demonstrate knowledge of thinking styles and their effects on teamwork
- Develop techniques for adapting one's own thinking style to enhance team efforts
- Exhibit cooperation and commitment to team success
- Identify team roles and responsibilities required for a specific team activity or project
- Perform all responsibilities associated with team roles for a given assignment
- Identify insights that lead to improved team performance

Information Gathering

Engineers must be able to gather appropriate information, using various sources and techniques needed to address issues at hand. They may gather information through visual observation, listening, measuring, reading, or otherwise sensing. This information gathering spans all stages of a design process from the initial statement of a need to the final evaluation of a product's acceptance, performance, or disposal. This requires skills in asking appropriate questions, identifying useful sources, and judging relevance of information. Engineers need to be able to prescribe and conduct measurements, scrutinize data, and interpret both technical and nontechnical information. They must be able to use appropriate technologies for accessing and filtering information.

Examples of measurable INFORMATION GATHERING outcomes are:

- Identify relevant questions for which information should be obtained
- Define criteria to be satisfied for information to be useful
- Identify sources and methods appropriate for obtaining information desired

- Demonstrate ability to locate information in libraries or other physical or electronic repositories of data
- Make measurements to gather information needed
- Select and use suitable instrumentation, communications equipment, software, and other aids for information gathering
- Apply appropriate methods for checking validity and making interpretations of information

Problem Definition

Engineers must be able to define problems with specific goal statements, criteria, and constraints which adequately specify the intended product, process, or system. They must first recognize that any number of possible design solutions exist. Then, beginning with an ill-defined statement of a client's need or desire, they must define clearly-stated, measurable requirements that a successful design solution will satisfy. Engineers must know the purpose and the characteristics of useful problem definitions and be able to create one for a given problem situation.

Examples of measurable PROBLEM DEFINITION outcomes are:

- Interpret requests to define deliverables expected from a client
- Define characteristics of useful problem definitions for design problems
- Prepare a clear goal statement with criteria specificity for determining success of a proposed design solution
- Refine goal statements and criteria as additional information necessitates changes

Idea Generation

Engineers must be able to select and effectively utilize techniques for generating ideas to meet needs arising throughout the design process. Thus, they must be aware of a variety of techniques for creative idea generation and understand when each is most useful. Individually or in groups, they must employ these methods skillfully to produce numerous ideas relevant to the need at hand.

Examples of measurable IDEA GENERATION outcomes are:

- Recognize opportunities for creativity throughout the design process
- Select the method most appropriate for generating ideas within the context of the need
- Employ individual and group methods in ways that produce many creative and relevant ideas
- Apply secondary techniques by which early lists of ideas stimulate additional creative ideas
- Apply techniques of synthesis to combine and extend ideas and to identify more creative and practical solutions
- Recognize applications which transfer ideas and solutions to other problems and situations

Evaluation and Decision Making

Engineers must be able to utilize critical evaluation and decision making methods to make competent design decisions. At many stages in the design process, ideas and concepts must be judged and compared to make decisions that directly affect the design. Additionally, the final product of the design must be evaluated against the criteria established as part of the problem definition to determine when the design is completed. Therefore, the engineer must be able to select the appropriate evaluation methods, execute them skillfully, make judgments relative to established criteria, and select the best path to follow. This requires skillful selection and use of analytical, experimental, and decision making tools and techniques.

Examples of measurable EVALUATION AND DECISION MAKING outcomes are:

- Select appropriate methods and tools for evaluation against specific criteria identified in problem definition
- Employ decision making techniques skillfully in selecting among multiple design options
- Perform computations or simulations needed to analyze performance of a design concept relative to design criteria
- Justify design decisions using economic, social, safety, environmental, performance, ethical, manufacturability, and other criteria
- Develop new evaluation/decision making methods to meet a specific need

Implementation

Engineers must be able to implement a design to a stage of usefulness to prospective clientele. This includes producing deliverables in a variety of forms throughout the design process. In any case, implementation performed by engineers requires them to receive and understand instructions (perhaps ones they personally developed earlier), perform necessary steps to fulfill them, and refine results to meet the needs or expectations of the client (internal or external to their team). This category focuses on deliverables.

Examples of measurable IMPLEMENTATION outcomes are:

- Select specific methods, materials, and other resources necessary for completion of requested deliverables
- Define manufacturing processes to produce a specified product
- Construct a required model or prototype
- Perform steps to produce requested deliverables on time
- Manage human and fiscal resources to achieve the desired product outcome

Integration

Engineers must be able to integrate the concepts and components of the design process into a coherent efficient whole. This requires understanding the iterative nature of the design process and repeating steps as needed for additional refinement. It also requires management of the design process to utilize member strengths and create synergism. Engineers must be able to schedule projects efficiently based on available personnel and other resources. Employing continuous improvement principles in the process also offers potential for improved design efficiency and products meeting or exceeding client expectations. This category focuses on the design process.

Examples of measurable INTEGRATION outcomes are:

- Explain the desirability and challenges of investigating a variety of possible solutions to a given problem situation
- Employ basic steps in the design process repeatedly to improve the design
- Schedule design steps and personnel to minimize time for design completion
- Practice continuous improvement methods to improve team performance and design product quality
- Make adjustments in processes as required to meet or exceed expectations of the client
- Practice personnel development to ensure that processes are performed well

ACHIEVING DESIGN COMPETENCE

Team-based design projects are a common means of developing design capabilities in students. Such projects are used by faculty to teach design because they simulate, to varying degrees, engineering design as found in professional practice. An implicit assumption being made by these faculty is that providing students experiences similar to those of practicing engineers will develop the skills they need for their professions. However, all too frequently faculty assigning design projects to student teams do not provide the structure and management framework needed to maximize the design education outcomes.

Planning Projects

Desired design competence can be achieved by strategically planning project assignments. The specific outcomes to be achieved will depend upon the level of student. Typically, students need to learn basic concepts and the design process prior to focusing on the product of the design. The instructor needs to clarify the type of outcomes sought both for creating an effective project and for helping students invest their energies appropriately.

The following steps, resembling those used in the engineering design process, will lead to a project that meets the objectives one establishes.

1. Define the general purpose of the project—the context of this project in the course, its length, its purpose (e.g., to introduce students to the design process, to provide a capstone experience, to give relevance to a concept).
2. Select a project topic that fits student interest and instructor's learning objectives.
3. Identify categories of design competencies to be developed in students (e.g., teamwork, idea generation).
4. Write a draft project assignment.
5. Define the steps students would follow in completing the project assignment.
6. Determine which of the competency categories is being developed and indicate whether each is a primary or secondary focus.
7. Refine the project (e.g., through strategic intervention of the instructor, oral or written reporting, critical thinking questions) to create the desired balance among competency category development.
8. Prepare a project assignment handout that structures the project to achieve the desired outcomes.

These steps in development of a design project assignment are illustrated by the example given below.

Project Purpose

A design project is being prepared for a freshman engineering class in which students are introduced to the engineering design process and to different fields of engineering. The faculty member defining this project is attempting to help students (a) see the value of teamwork, (b) discover the need for clear problem definition in design, and (c) recognize the complexity of biological systems for which design solutions need to be developed.

Prior to this project assignment, students have been introduced to the engineering design process. They also have completed one 3-week project on a different topic. A period of 3 weeks (9 hours of class time) is available for this project.

Project Topic

This group of students has interest in space exploration and in biological systems engineering. The instructor has developed a computer simulation that models the ecological balance of a space station environment, and the simulation is easily learned by high school or college students. Thus, the project will engage students in using this simulation to explore biological system balance in a space station.

Categories of Competence

The primary categories of design competence to be developed in this project are: communication, teamwork, problem definition, idea generation, evaluation and decision making. The instructor wants students especially to grasp the importance of establishing a clear definition of the problem and recognizing its value for evaluating possible solutions to the problem. They must be able to defend their proposed solution. They also need to understand and use the overall design process.

Draft Project Assignment

A space station has been designed for long-term human habitation. In this balanced ecosystem humans, fish, plants and microbes live symbiotically such that waste products of one life form support other life forms. After the space station has been populated and the ecosystem has reached a state of balance, a desertion of 10% of the humans causes the ecosystem a sudden imbalance.

As a team of four, define the steps necessary to bring the system back into balance. SpaceStation®, a computer simulation of this ecosystem, is available to explore and evaluate proposed solutions (Pitts and Davis, 1996). Your team will prepare a poster to present your solution to this design problem.

Steps in the Design

The following are steps freshmen students likely would follow in developing their design solution:

1. Explore the simulation to understand issues relevant to ecosystem balance.
2. Define a statement of the problem with criteria to be satisfied for a viable solution.

3. Review the simulation to identify specific parameters that can be controlled.
4. Develop plans for experiments that will yield information needed to bring the ecosystem into balance.
5. Conduct the experiments and gather appropriate data.
6. Propose the best solution(s).
7. Evaluate the proposed solution(s) to determine success in meeting criteria.
8. Plan a poster presenting the team's design process and solution.
9. Prepare the poster to communicate effectively.
10. Make oral presentation of the team's solution.

Determine Competencies Developed

The matrix of competency categories vs. steps shown below illustrates the extent to which each competency is addressed in this project. P is used to denote a primary objective and S to denote a secondary one. Note that communication and teamwork are used in nearly every step of the process, but other competency categories appear in only one or two steps. As students progress through the project, they exercise different categories of competencies.

Competencies: Steps	Com-muni-cation	Team-work	Infor-mation Gathering	Problem Definition	Idea Generation	Evaluation & Decision Making	Implemen-tation	Integra-tion
1. Explore simulation	S	S	P					
2. Define problem	S	S		P				
3. Identify parameters		S	P	S	S			
4. Plan experiment	S	P			P	P		
5. Conduct experiment		S	S				P	
6. Propose solutions	S	S			P	S		
7. Evaluate solutions		S				P		
8. Plan poster	P	S						S
9. Prepare poster	S	S					P	
10. Make presentation	P	S					S	S

Refine Project Assignment

Reviewing the objectives behind the project and examining the matrix above, one sees that the problem definition competency category needs more attention. Students need to understand the relationship between the problem definition and the value of the solution. In order to achieve this depth of understanding of problem definition, another step is proposed to make it more specific. In this new step (7a), students will be asked to identify components (specific criteria) of the problem definition and make each component quantifiable (e.g., require that fluctuations in oxygen content remain within ±2% of the target level). This will provide a better basis for judging the viability of their proposed design solutions. To add greater focus to development of the problem definition competency category, the faculty member can remind the students that their poster needs to reflect the use of problem definition constraints in their presentation of their solution.

Clearly, effective projects require much planning.

Prepare Assignment Handout

The project assignment provides students a framework for guiding their energies toward completion as intended by the instructor. Thus, the assignment handout materials for students must clearly define what is important to the instructor and what constraints are to be observed as they complete the project. The following elements are important items in student design project handouts:

- Title—descriptive title to use in making reference to this assignment
- Abstract—brief statement of what the student is to expect from this project
- Objectives—learning outcomes planned, may cite competencies being developed
- Tasks (steps)—list of steps to be followed, may include questions to be addressed to guide selected steps
- Product expected—the deliverables that will be required and graded
- Evaluation technique—criteria for grading, including individual vs. team issues
- Resources and constraints—what is available as resources, including time, people, materials, etc.

A sample design project assignment handout is given in the appendix.

Assessing Team Design Projects

Central to effective learning is the identification of learning outcomes and definition of the manner in which their achievement will be assessed. Educational outcomes from team design projects generally fall into three major types: product, process, and individual learning. Product outcomes are the completed design, in whatever form this takes. Process outcomes are the students' abilities to perform effectively their specific team roles and their collective steps of the design process. Individual learning outcomes are increases in understanding about the design process itself and the technical details of the design solution.

Assessment needs to be defined clearly in the student handout for the project. This definition focuses the students' energies on deliverables that will be graded. It also reminds the instructor what the important outcomes are. The result of this assessment is a measure of the students' development of educational outcomes planned for this project.

SUMMARY

A competency-based approach to engineering design education can be achieved by (a) defining engineering design competencies or outcomes desired, (b) structuring design projects to fit desired design competency development, and (c) selecting and using assessments that fit the types of outcomes sought. The planning must be completed prior to the start of the project and communicated to students to direct their energies.

By appropriately structuring steps in design projects, up to eight categories of design competencies are employed by students and their levels of proficiency in these will increase. Instructors can use a matrix approach in their analysis of design projects to refine them for achieving the learning outcomes they want developed. This clarifies prerequisite skills needed and where students' energies will be spent, providing clear indications of ways to make projects more effective for design education.

The use of design projects throughout a curriculum offers opportunities to develop engineering design competence in a structured way. Projects can be used with freshmen to introduce design terminology, processes, and skills. Later projects can be structured to refine these competencies. Planning design education with competencies clearly articulated provides a rational approach to effective design education.

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APPENDIX

DESIGN PROJECT

RESTORING ECOSYSTEM EQUILIBRIUM FOR SPACE STATION

INSTRUCTOR'S GUIDE

KEYWORDS

Engineering design, system dynamics, computer simulation, SpaceStation®, ecosystem, design criteria, biological systems

DESIGN COMPETENCIES ***(P = PRIMARY, S = SECONDARY)***

Communication	P	poster, oral presentation
Teamwork	S	team-based project, team grades
Information gathering	S	computer simulation to learn about biological system dynamics
Problem definition	P	emphasis on defining problem with specific criteria
Idea generation	S	seek ideas for possible solutions
Evaluation & decision making	S	simulation to test ideas and select best idea for solution
Implementation	S	conduct simulations, prepare poster
Integration		

PREREQUISITES

- knowledge of team roles and responsibilities of each in teamwork
- knowledge of steps used in the engineering design process

CLASSROOM PROCEDURES

- Assign teams of four students each.
- Hand out Design Project assignment.
- Provide brief written and oral description of the space station's ecosystem, factors affecting its balance, and capabilities of SpaceStation® software.
- Ask teams to assign roles to members and to develop a schedule.
- Have students report their schedule to entire class at end of first period.

INSTRUCTOR TIPS

- Assign teams with underrepresented students in pairs within teams of four.
- Provide student teams clear definitions of what is expected and when; help them develop a schedule to ensure that they will complete their assignment on time.
- Remind students of grading criteria before starting poster
- Show teams examples of posters developed by other students, if available.

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DESIGN PROJECT

RESTORING ECOSYSTEM EQUILIBRIUM FOR SPACE STATION

STUDENT HANDOUT

ABSTRACT

In this project you will work as a team to design a process by which balance can be restored to a space station ecosystem to preserve the lives of humans and other life forms. You will use a computer simulation to investigate interactions among life forms, generate solution ideas, and evaluate your ideas. Finally, you will present your solution to the class.

OBJECTIVES

1. Students will be able to develop a problem definition with specific statements of criteria to be satisfied for a successful solution.
2. Students will judge the merit of their design solution by criteria established in the problem definition.
3. Students will recognize value of computer simulation in making design decisions in complex systems.

TASKS

1. Explore the SpaceStation® simulation to understand ecosystem dynamics
2. Define the problem to be solved, including specific criteria for solution
3. Identify parameters that can be varied and influence ecosystem dynamics
4. Plan an experiment to determine actions that can bring the system into balance
5. Conduct simulation experiments and gather appropriate data
6. Propose control solutions that have merit for achieving system balance
7. Conduct simulations to evaluate each of your proposed solutions; tabulate how well (quantitatively) each criterion was met in each solution
8. Plan a poster that describes your solution process and your solution
9. Prepare the poster for an attractive, effective presentation
10. Present your results to the class at the assigned time

DELIVERABLES

- Poster presentation to class
- Response to oral questions related to grading criteria

RESOURCES

Your team, 3 weeks, computer lab and SpaceStation® software

CRITERIA FOR GRADING

Team grades will be assigned based on:

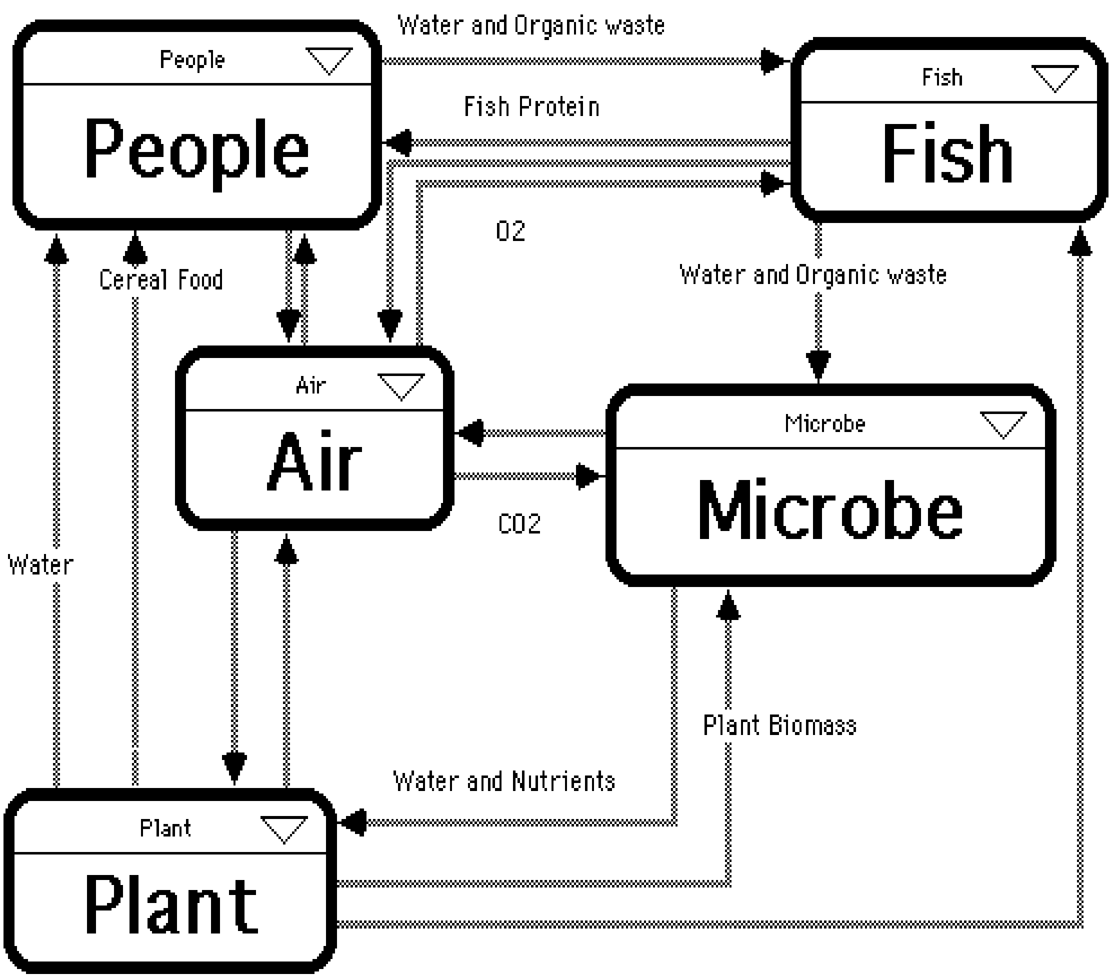
1. Specificity and appropriateness of criteria in problem definition
2. Extent to which solution is defended based on criteria in the problem definition

3. Students' abilities to describe the value of the simulation to the design process

SPACE STATION DESCRIPTION

Scientists and engineers within the National Aeronautics and Space Administration (NASA) are conducting research which will lead to the development of advanced life-support systems that use plants, fish and microbes to solve long term life-support problems in space. The Controlled Ecological Life-Support System (CELSS) is a biological solution to life support that consists of a complex, extensively-controlled, bioengineered system that relies on plants, fish, and microbes to provide principal elements such as gas exchange, food, and potable water reclamation.

The computer simulation SpaceStation® uses simplified relationships defined by the CELSS researchers. SpaceStation biology consists of the organisms—plants, fish, people and microbes—that share four substances: oxygen, carbon dioxide, water and organic waste. The space station biology modeled in the program is highly interrelated (as shown below).



Flowchart of relationships used in the space station simulation.

In the simulation, the people on the station consume oxygen, fish protein and cereal grain, and produce carbon dioxide and organic waste (in water passed to the fish). The fish consume oxygen and cereal grain, and produce carbon dioxide, organic waste (in water passed to the microbes) and protein. The microbes consume carbon dioxide and organic waste, and produce oxygen and plant nutrients (in water passed to the plants). The plants consume carbon dioxide and plant nutrients, and produce oxygen and cereal grain. The growth and/or death of any organism depends on the state of the other organisms in the system.

People and fish share the oxygen and cereal grain in the station, and both produce carbon dioxide and organic waste. Both organisms will suffer (slower growth or death) if the quantities of oxygen or grain decrease too far, or if the quantities of carbon dioxide or organic waste accumulate. The interaction between people and fish is complicated by the predator/prey relationship.

The interaction between plants and microbes is less complicated. The plants and microbes share the carbon dioxide in the station. The plants are dependent on the microbes to convert organic waste into plant nutrients, and the animals that produce the organic waste depend on the plants for food.

Weaving the space station relationships into a computer simulation was accomplished using the STELLA™ simulation package. STELLA emphasizes detailing the relationships between elements in the simulation. The package uses a graphical interface to write simulations and display results.

Details of the SpaceStation® simulation are found in an article describing the use of this simulation with freshmen students (Pitts and Davis, 1996).

REFERENCE

Pitts, M.J. and D.C. Davis. 1996. "SpaceStation©—Computer Simulation Tool Demonstrating Biological Systems." *Journal of Engineering Education* (in press).

BIOSKETCH

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