



Problem Solving

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INTRODUCTION

Problem solving is a central educational objective within every country's school program. Educators and policy makers are especially concerned about students' competencies for solving problems in real-life settings. That means understanding the information given, identifying the critical features and their interrelationships, constructing or applying an external representation, solving the problem, and evaluating, justifying and communicating their solutions. The processes of problem solving, so conceived, are found across the curriculum, in mathematics, the sciences, language arts, the social sciences, as well as in many other content areas. Problem solving provides a basis for future learning, for effectively participating in society and for conducting personal activities.

While problem solving is an ever-present human activity, the development of a framework to outline its components and develop measures of student performance is not easy. Several writers have commented on the lack of an agreed-upon comprehensive definition of problem solving (*e.g.*, Frensch & Funke, 1995; O'Neil, 1999). Yet there is a large body of literature on learning and related topics (Bransford, Brown, & Cocking, 1999; PEG, 2001) that discusses problem solving, often without giving an explicit definition of the term in context.

The OECD/PISA assessment programme develops, administers and interprets surveys of student literacy on an international basis. The expressed purpose of this programme is to monitor and report on student literacy levels in a number of domains. However, the focus of the programme is not on reporting the level of curricular knowledge the students have acquired. Rather, the programme focuses its efforts on describing the capabilities that students have in real-world situations that call for applications of their reading, science and mathematics knowledge and skills. Besides collecting data reflecting student performance in these literacy areas, the OECD/PISA 2003 assessment also collects data related to students' cross-disciplinary problem solving capabilities.

BACKGROUND

To prepare the OECD/PISA problem solving framework, an examination was made of extant, research-based programmes assessing student capabilities in solving problems set in novel surroundings. Several studies were identified as providing interesting results or utilising innovative formats. Among these were the following:

- the “clinical reasoning test” based on case studies in patient management (Boshuizen *et al.*, 1997);
- the “overall-test” of complex, authentic decision making in business education (Seger, 1997);
- the “what if – test”, which addresses intuitive knowledge used in exploring simulations of science phenomena (Swaak & de Jong, 1996).



A more general review of research identified a range of relevant initiatives. For example, within mathematics there is a long tradition of the study of problem-oriented thinking and learning (Hiebert *et al.*, 1996; Schoenfeld, 1992) and related assessment strategies (Charles, Lester & O’Daffer, 1987; Dossey, Mullis, & Jones, 1993). In psychology, studies detail the importance of student knowledge of inductive reasoning (Csapó, 1997) and analogical reasoning (Vosniadou & Ortony, 1989). Klieme (1989) provides an integrated discussion of assessing problem solving from an educational, cognitive-psychological and measurement perspective. Collis, Romberg and Jurdak (1986) developed a problem solving test that used “super items,” each of which was composed of a sequence of questions addressing subsequent levels of cognitive complexity. Another set of efforts deals with differentiating task complexity levels. Most of these build on the seminal work by Bloom, Hasting and Madaus (1971). Other promising efforts include the TIMSS performance expectations (Robitaille & Garden, 1996) and the various PISA assessment frameworks (OECD, 1999 & 2000).

In recent years there has been an increased interest in assessing problem solving as a cross-disciplinary competency, yet reviews of problem solving assessment (Klieme 2000; Mayer 1992) reveal no frameworks for it. During the past five years there have been several attempts to implement some cross-disciplinary problem solving in large-scale assessments. Trier and Peschar, working for OECD-Network A (1995), addressed problem solving as one of four important cross-disciplinary competencies. They conducted a feasibility test for such an assessment. Their sample “item” was an essay-like planning task, in which the subjects had to plan a trip for a youth club. While they were able to gather student data, they encountered difficulties in scoring the responses.

Working independently, Frensch and Funke (1995) devised several experimental variants of planning tests, while Klieme, *et al.* (in press) developed a multiple-choice test of problem solving competence for a large-scale assessment programme for one of the German federal states. In this assessment, the planning task was decomposed into action steps (clarifying goals, gathering information, planning, making decisions, executing the plan and evaluating the result). Each task was addressed by a sequence of items that required subjects to judge the consistency of goals; to analyse maps, schedules or other documents; to reason about the order of activities; to diagnose possible errors in the execution of actions; or other problem solving actions. A similar project approach to measuring student problem solving competencies is being considered for inclusion in the International Survey of Adults (ISA), formerly known as International Adult Literacy and Life Skills Survey (ALLS) (Binkley, *et al.*, 1999).

In a German national option involving 650 15-year-old students in PISA 2000, a set of eight cross-disciplinary problem solving assessments was implemented and validated (Klieme, 2000). The intention was to use as much input from basic cognitive research on problem solving as possible for the development and validation of new instruments. Results demonstrated the feasibility of both paper-and-pencil and computer-based instruments for cross-disciplinary problem solving assessment. The findings included that:



- cross-disciplinary problem solving competencies can be distinguished from domain-related competencies (mathematical literacy, scientific literacy and reading literacy);
- several indicators of analytical problem solving competence, including the “tyre pump task” designed by Harry O’Neill (1999), the “project approach” and a test with analogical transfer-problems, loaded on a common factor.

The objective of the OECD/PISA problem solving framework was to extend the prototypes developed in the feasibility and research studies to a workable model for a large-scale assessment as part of PISA 2003.

DEFINITION OF THE DOMAIN

Richard Mayer (1992) noted in writing about assessments of problem solving that designers must:

- require the problem-solver to engage in higher order thinking (or cognitive) processes with the goal of reaching solutions for realistic, authentic tasks that require the integration of skills; and
- confront the test taker with non-routine problems that require the student to invent a novel solution strategy.

The assessment of problem solving should extend into non-routine situations drawing on prior knowledge, merging content areas and requiring the integration of concepts, representations and processes on the part of test-takers.

Most people involved in the study of problem solving in research or practice-based settings, using one conception or another of the field, agree that in describing student problem solving, the major focus is on describing the cognitive acts students make in addressing, solving and reporting solutions. As such, PISA 2003 takes the following as its definition of problem solving:

Problem solving is an individual’s capacity to use cognitive processes to confront and resolve real, cross-disciplinary situations where the solution path is not immediately obvious and where the literacy domains or curricular areas that might be applicable are not within a single domain of mathematics, science or reading.

Several terms in this definition need further explanation:

... cognitive processes ...

This aspect of problem solving deals with the various components of the problem solving act and the cognitive processes underlying them, including application of understanding, characterising, representing, solving, reflecting and communicating. These processes will be described in more detail in the next section.



... *cross-disciplinary* ...

In relation to problem solving, the current OECD/PISA assessments address problem solving within each domain. The frameworks of reading, mathematical, and scientific literacy assess problem solving skills within each of these domains. The OECD/PISA assessment of problem solving extends the consideration of student competencies to a broader range of problem solving items falling across the boundaries of traditional curricular areas.

... *real* ...

The above definition of problem solving emphasises solving real-life problems. These problems call on individuals to merge knowledge and strategies to confront and resolve a problem readily identifiable as arising from real-life situations. Such problems call on people to move among different, but sometimes related, representations and to exhibit some degree of flexibility in the way they retrieve and apply their knowledge. These problems call for students to make and communicate decisions that appear to have immediate ramifications for those involved.

ORGANISATION OF THE DOMAIN

With the OECD/PISA definition of problem solving, the tasks must necessarily depend on context- or domain-specific knowledge and strategies. Therefore, the contexts, domains and situations in which problem solving is assessed have to be selected very carefully. The following components need to be considered:

- *Problem types.* A general definition of problem solving would cover a wide spectrum of problem types. For the purpose of the PISA 2003 assessment, three problem types have been chosen: *decision making*, *system analysis and design*, and *trouble shooting*. A detailed discussion of these is included in the next section. These three problem types cover most of the problem solving processes generally identified within the problem solving domain. OECD/PISA problem solving assessment does not include types such as interpersonal problem solving or argumentative text analysis.
- *Problem context.* This component involves the positioning of the problems relative to the students' experience with problem solving. In particular, the settings selected should be some distance from the classroom setting and students' school curricula. Hence, the PISA 2003 problems should employ contexts that involve personal life, work and leisure, and community and society. These contexts cover a continuum running from personal space to civic awareness, including both curricular and extra-curricular contexts.
- *Disciplines involved.* To reflect the real-life problem solving focus, the PISA 2003 problem solving domain will cover a wide range of disciplines including mathematics, science, literature, social studies, technology and commerce. As such, problem solving complements the main OECD/PISA domains of mathematical, scientific and reading literacy. The knowledge and skills



involved in a problem solving task will not be restricted to any one of these domains, thus avoiding possible duplication.

- *Problem solving processes.* To what degree is the student able to confront a particular problem and begin to move toward a solution? What evidence does the student offer of understanding the nature of a problem, of characterising the problem through identification of variables and relationships, of selecting and adjusting representations of a problem, of moving to a solution, of reflecting on the work or of communicating the results?
- *Reasoning skills.* Each of these problem solving processes draws not only upon problem solvers' knowledge bases, but also their reasoning skills. For example, in understanding a problem situation, the problem solver may need to distinguish between facts and opinion. In formulating a solution, the problem solver may need to identify relationships between variables. In selecting a strategy, the problem solver may need to consider cause and effect. In communicating the results, the problem solver may need to organise information in a logical manner. These activities often require analytic reasoning, quantitative reasoning, analogical reasoning and combinatorial reasoning skills. These reasoning skills form the core of problem solving competencies.

Box 4.1 ■ TYPES OF REASONING SKILLS

Analytic reasoning is characterised by situations where the learner must apply principles from formal logic in determining necessary and sufficient conditions, or in determining if implication of causality occurs among the constraints and conditions provided in the problem stimulus.

Quantitative reasoning is characterised by situations where the learner must apply properties and procedures related to number sense and number operations from the discipline of mathematics to solve the given problem.

Analogical reasoning is characterised by situations where the learner must solve a problem with a context similar to a problem the learner is familiar with, or includes a problem base which the learner has solved in the past. The parameters or the context in the new stimulus material is changed, but the driving factors or causal mechanism is the same. The learner should be able to solve the new problem by interpreting it in light of past experience with the analogous situation.

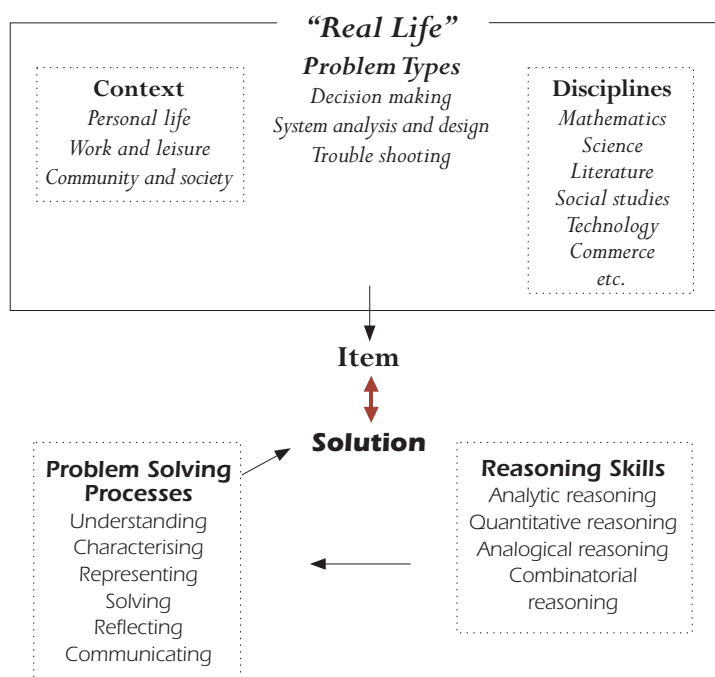
Combinatorial reasoning is characterised by situations where the learner must examine a variety of factors, consider all combinations in which they can appear, evaluate each of these individual combinations relative to some objective constraint and then select from or rank order the combinations.



Thus, the act of problem solving is the amalgam of many different cognitive processes that are orchestrated to achieve a certain goal that could not be reached, at least obviously, by simply applying a well-known procedure, process, routine or algorithm from a single subject area. Problem solving competence can be described in terms of students' abilities to create and monitor a number of processes within a certain range of tasks and situations. Problem solving assessment strives to identify the processes used in a variety of situations and content areas and to describe and quantify, where possible, the quality of the products of the students' work.

The elements of the PISA 2003 assessment of problem solving are shown in Figure 4.1. The relationships illustrate how such an assessment draws both on context and content knowledge from various fields, as well as on competencies found in the content areas and in problem solving as a domain in itself.

Figure 4.1 ■ Visualisation of the key components of problem solving framework



Problem types

For cross-disciplinary problem solving assessment in PISA 2003, it was decided to limit the assessment of student capabilities to three broad areas of problem solving, which will be referred to as "problem-types". These three problem types are: *decision making*, *system analysis and design*, and *trouble shooting*.

Decision making, *system analysis and design*, and *trouble shooting* are generic problem solving structures that capture important aspects of the everyday, real-life, analytical reasoning that we would like to assess in the assessment programme. They provide an alternative to the content domains of the reading, mathematical



and scientific literacy assessments. In those assessments, there is a well-defined knowledge domain that provides the needed structure to bound the assessment. In testing problem solving, the emphasis is on process rather than on domain knowledge. However, processes cannot be assessed without being attached to some kind of structure. The three proposed problem types provide the generic structures within which problem solving processes can be assessed.

Decision making

Decision making problems require students to understand a situation involving a number of alternatives and constraints, and to make a decision that satisfies the constraints. For example, in Problem Solving Unit 1: Say No To Pain, students are asked to decide which of a selection of pain killers is the most suitable one, considering the patient's age, symptoms and other medical conditions.

Decision making tasks such as the above typically involve comprehending the information given and the demands of the task, identifying the relevant features or constraints that must be met, creating a representation of the problem or alternatives, making a decision that meets the constraints, checking to see that the solution meets the constraints and then communicating or justifying the decision. In *decision making* tasks of this type, the student needs to select an alternative from a number of given ones. In doing this, the student must usually combine information from a number of diverse sources (combinatorial reasoning) and select the best solution.

A *decision making* problem will be more difficult if it is more complex. For example, the decision to buy a car becomes more difficult when the amount of information to be analyzed increases, the information involves a number of different representations that must be linked, or a greater number of constraints must be attended to. Some students may be able to deal with easy *decision making* tasks but fail when the complexity of a task increases.

When the complexity of a *decision making* task is high, external representations can become very useful. In Problem Solving Unit 1: Say No to Pain, such a representation is already constructed, in the form of a table. For other *decision making* tasks, students may be required to create such representations, in the form of tables, diagrams, graphs, etc. Students' abilities to create relevant representations or to apply a given representation, such as making or interpreting a graph, are factors in their performances on *decision making* tasks. Once a representation is constructed or applied, the student must select, relate and compare the information as organised by the representation and choose the best alternative.

Problem Solving Unit 1

SAY NO TO PAIN

It is not easy to choose the right pain killer for occasional aches and pains, as there are so many different brands of pain killers on the market, all claiming to be the right one for you.

The Care Medical group provides the following information about 4 different painkillers:



Pain killer Name	Description	For the Relief of Symptoms	Dosage	Caution Notes
Aquaspirin	100% dissolvable aspirin tablet. Good for people who cannot face taking pills.	Headache; Muscle pain; Dental pain; Back pain; Sore throat; Reduce inflammation and fever.	Adult and children over 12 years of age: 1 to 2 tablets dissolved in half a glass of water every 4 hours as needed. Do not exceed 8 tablets in 24 hours. Children under 12 years of age: Do not administer Aquaspirin to children under 12 years of age.	Prolonged use could be harmful. Should not be taken by a person on a low sodium diet.
Paracem	100% paracetamol. Suitable for breastfeeding mothers and asthmatics. Does not cause stomach irritations like aspirin.	Headache; Backache; Toothache; Muscular pain; Arthritis; Reduce fever.	Adult and children over 12 years of age: 1 to 2 tablets every 4 hours as needed. Children under 12 years of age: 0.5 to 1 tablet every 4 hours as needed.	Prolonged use could be harmful.
NoAx	Each tablet contains 25mg of Diclofenac Potassium. Suitable for the relief of acute, painful and inflammatory conditions. Pain relief is usually within 15 to 30 minutes.	Bruises; Neck pain; Back pain, Sprains and strains; Migraine; Pain after surgery.	Adult and children over 14 years of age: 1 to 2 tablets every 8 hours. Do not exceed 6 tablets a day. Children 14 years and under: Children 14 years and under should not take NoAx.	Do not take NoAx on an empty stomach. Check with your doctor if you suffer from asthma, or if you are taking any other medication. Possible side-effects: dizziness, swelling of feet.
Reliefen	Each tablet contains 200mg of ibuprofen. It is gentler on the stomach than aspirin.	Headache; Muscle & rheumatic pain; Dental pain; Cold symptoms; Backache; Reduce fever & inflammation.	Adult and children over 12 years of age: 1 to 2 tablets every 4 - 6 hours. Do not exceed 6 tablets in 24 hours. Children 12 years and under: Reliefen is not suitable for children 12 years and under.	If you suffer from asthma, kidney disorder, are allergic to aspirin or are pregnant, you should consult your doctor before taking Reliefen.



Problem Solving Example 1.1

From the information given, rank the four pain killers from the weakest to the strongest. (Write the numbers 1 to 4 in the boxes, with 4 as the strongest).

- Aquaspirin
- Paracem
- NoAx
- Reliefen

Scoring

Full credit

Code 1: Answers that present 2, 1, 4, 3 in that order.

No credit

Code 0: Other responses.

Problem Solving Example 1.2

Identify **two** pain killers that may cause more stomach irritation than the other two.

- A. Aquaspirin
- B. Paracem
- C. NoAx
- D. Reliefen

Scoring

Full credit

Code 1: Answers that indicate A and C as the two pain killers that may cause stomach irritation.

No credit

Code 0: Other responses.

Problem Solving Example 1.3

Michael's mother took some Reliefen tablets for a cold and headache. She took two tablets at 8 am, one tablet at 1 pm and two tablets at 6 pm. Before going to bed at 11 pm, how many tablets could she take, according to the dosage instructions?

Scoring

Full credit

Code 1: Answers that specify "one tablet", so that the total does not exceed six tablets within 24 hours.

No credit

Code 0: Other answers.



Problem Solving Example 1.4

Choose the pain killer most suitable for each of the following patients, based on the information given.

PATIENT	CIRCLE THE MOST SUITABLE PAIN KILLER
Emma, a 10-year-old child with a cold and fever.	Aquaspirin/Paracem/NoAx/Reliefen
George, a 13-year-old asthmatic boy with a sprained ankle, needing a pain killer to reduce pain and inflammation.	Aquaspirin/Paracem/NoAx/Reliefen
William, a 45-year old machine operator, needing a long-lasting pain killer for back pain that he can take each day.	Aquaspirin/Paracem/NoAx/Reliefen
Susan, a breastfeeding mother, suffering from a headache.	Aquaspirin/Paracem/NoAx/Reliefen

Scoring

Full credit

Code 1: Answers that specify Paracem, Aquaspirin, Reliefen, Paracem, in that order:

No credit

Code 0: Any other combination of answers.

After making a decision, students must be able to evaluate, justify and communicate this decision to an outside audience. The ability to justify and communicate a problem solution is an important aspect of students' *decision making* capabilities.

To summarise, *decision making* tasks require understanding the given information, identifying the relevant alternatives and the constraints involved, constructing or applying external representations, selecting the best solution from a set of given alternatives and evaluating, justifying or communicating the decision.

System analysis and design

System analysis and design problems require a student to analyse a complex situation in order to understand its logic and/or to design a system that works and achieves certain goals, given information about the relationships among features of the problem context. For example, in Problem Solving Unit 2: Managing CD Sales, the student is asked to analyse a record keeping system for managing CD sales in a music store.



A *system analysis and design* problem is different from a *decision making* problem in at least two critical aspects: *i*) the student is asked to analyse a system or design a solution to a problem rather than to select one of a set of alternatives; and *ii*) the situation described usually consists of a complex system of interrelated variables, where one variable influences others and the solution is not always clear-cut. In other words, *system analysis and design* problems are characterised by the dynamic nature of the relationships among the variables involved and the possible non-uniqueness of the solution. These types of problems occur often in disciplines such as economics or environmental sciences. In *decision making* tasks, the variables typically do not interact in such complex ways, the constraints are more clear-cut and the decisions are easier to justify.

System analysis and design tasks usually require identifying related variables and finding out how they will interact. In such problem settings, students must be able to analyse complex situations and determine the relationships defining the systems, or to design a system that satisfies the given relationships and achieves the relevant goals. The ability to evaluate, justify and communicate a solution to a *system analysis and design* problem is also an integral part of the entire process.

As was seen in examining *decision making* problems, the difficulty of a *system analysis and design* problem is also affected by its complexity. The more complex a situation (in terms of the number of variables, but also in terms of their interrelations), the greater the difficulty of the problem solving task. The creation of a representation or the application of a given or known representation is a necessary part of the process of solving the problem.

In Problem Solving Unit 2: Managing CD Sales, the student is asked to identify variables that are relevant for CD sales and to analyse the relationships among them to determine the best way to organise information. This task also requires students to work out methods of information retrieval using logical reasoning.



Problem Solving Unit 2
MANAGING CD SALES



The Fine Melody CD store is developing a system for keeping records of music CDs sold by the store. They prepared two record sheets on the computer as shown below:

Record Sheet 1: Attributes of each CD (One line per CD)

CD Serial ID Number	Title of CD	CD Company
14339	Spring Carnival	NAXA
10292	Hits of the '90s	FineStudio
00551	Arias for Opera Lovers	DigiRec

Record Sheet 2: Attributes of each track on CD (One line per track)

CD Serial ID Number	Track number	Track Name
14339	1	Spring Fever
14339	2	Leap into Spring
14339	3	Midnight Rhythm
10292	1	Best Dance in Town

Problem Solving Example 2.1

Which record sheet (1 or 2) should each of the following attributes be added to?

ATTRIBUTE	EXAMPLE ENTRIES	CIRCLE "RECORD SHEET 1" OR "RECORD SHEET 2"
ARTIST/BAND/ ORCHESTRA	Faye Weber; Berlin Philharmonic	Record Sheet 1/Record Sheet 2
PRICE OF CD	15 zeds; 25 zeds for a set of two.	Record Sheet 1/Record Sheet 2
STOCK STATUS	On order; In stock	Record Sheet 1/Record Sheet 2
COMPOSER	Warren Jones; Li Yuan	Record Sheet 1/Record Sheet 2

**Scoring**

Full credit

Code 1: Answers that specify Record Sheet 2, Record Sheet 1, Record Sheet 1, Record Sheet 2, in that order.

No credit

Code 0: Any other combination of answers.

Problem Solving Example 2.2

Add **two** attributes for Record Sheet 1, and **two** attributes for Record Sheet 2, with example entries. Do not include attributes that have already been mentioned.

Scoring

List of attributes for Record Sheet 1:

- copyright/release year for CD, *e.g.*, ©1998.
- total CD playing time, *e.g.*, 78 minutes.
- CD categories: classical, popular, alternative.

List of attributes for Record Sheet 2:

- track playing time, *e.g.*, 5'32".
- year/place of recording, *e.g.*, March 1998, Prague.
- lyric writer, *e.g.*, Sharon Green.

Full credit

Code 2: Answers that include:

- two attributes for Record Sheet 1 from the above list of attributes.
AND
- two attributes for Record Sheet 2 from the above list of attributes.

Partial credit

Code 1: Answers that are incomplete, such as mentioning:

- only two attributes for Record Sheet 1
OR
- only two attributes for Record Sheet 2
OR
- one attribute for Record Sheet 1 and one attribute for Record Sheet 2;
OR
- two attributes for each Record but with no example entries.

No credit

Code 0: Other answers.



Problem Solving Example 2.3

The record keeping system allows users to search for particular CDs. The following shows how search commands are written, using brackets () and the key words: “AND” and “OR”:

(1) To find all CDs under 15 zeds with recordings made by vocalist Irena Emile, write the following search command:

(Price < 15) AND (Artist=Irena Emile).

(2) To find all CDs with recordings of Beethoven’s Fifth Symphony recorded by the Boston or Chicago Symphony Orchestras, write the following search command:

(Track name=Beethoven’s Fifth Symphony) AND (Orchestra=Boston OR Chicago).

Write a search command to find all of the CDs produced by the recording companies NAXA or DigiRec of the recordings of the song “Last Night I Had a Dream”.

Scoring

Full credit

Code 1: Answers that include:

(Track=Last Night I Had a Dream) AND (Company=NAXA OR DigiRec).

Note that the emphasis is on the placement of AND, OR and the brackets. The actual texts and order of the brackets are not important. The exact form of the key words such as “track” and “company” is not important. Thus, “title” is acceptable instead of “track name”, “producer” instead of “company”, etc.

No credit

Code 0: Other answers.

Evaluation, justification and communication of a solution are very important parts of the problem solving process in a *system analysis and design* task. The solution to such a task is generally not unique or obvious and there are possible advantages and disadvantages associated with each possible solution.

To summarise, a *systems analysis and design* task usually requires understanding the complex relationships among a number of interdependent variables, identifying their critical features, creating or applying a given representation, analysing a complex situation or designing a system so that certain goals are achieved. It also normally involves a good deal of checking and evaluating as the student moves through the various steps along the way to an analysis or design.



Trouble shooting

Trouble shooting problems require a student to comprehend the main features of a system and to diagnose a faulty, or under-performing, feature of the system or mechanism. For example, in Problem Solving Unit 3: Bicycle Pump, Jane is asked to find out why air is not coming out of her bicycle tyre pump. Despite the fact that she repeatedly pulled up and pushed down on the handle-piston assembly of the pump, no air was pumped out. Jane will not be able to make her diagnosis unless she understands how the bicycle tyre pump works and, more specifically, the function of the inner and outer valves and the piston in transferring air from outside of the pump into the bicycle tyre attached to the pump hose.

Trouble shooting tasks can be clearly distinguished from *decision making* and *system analysis and design* tasks. *Trouble shooting* problems involve neither selecting the best of a set of given options, nor the design of a system to fit a given set of requirements. Rather, *trouble shooting* tasks require the understanding of the logic of a causal mechanism, such as the workings of a physical system or a procedure. For example, a retail company needs to find the causes for their declining sales figures or a computer programmer needs to find the error in a program.

Despite the differences in the structures of the three problem types, the student solving a *trouble shooting* task must also understand how the device or procedure works (*i.e.*, understand the mechanism), identify the critical features for the diagnosis of the specific problem he or she is asked to solve, create or apply the relevant representations, diagnose the problem, propose a solution and, when the situation requires it, execute the solution.

Representation is very important in *trouble shooting* problems because they often require the integration of verbal and pictorial information. In Problem Solving Unit 3: Bicycle Pump, Jane must integrate the pictorial and verbal information to arrive at an understanding of the mechanism of the pump. In other situations, the student may need to create a pictorial representation out of a verbal description or describe verbally a drawing that demonstrates how a device works. The ability to move flexibly from one representation to another is an important aspect of problem solving that is often involved in *trouble shooting* problems. Finally, evaluation, justification and communication are as important in *trouble shooting* problems as in the other problem types. For example, in Problem Solving Example 3.2, reasons have to be given to support claims.

To summarise, *trouble shooting* tasks involve diagnosing, proposing a solution and, at times, executing this solution. The tasks require the student to understand how a device or procedure works, to identify the relevant features for the task at hand and to create a representation or apply a given representation.

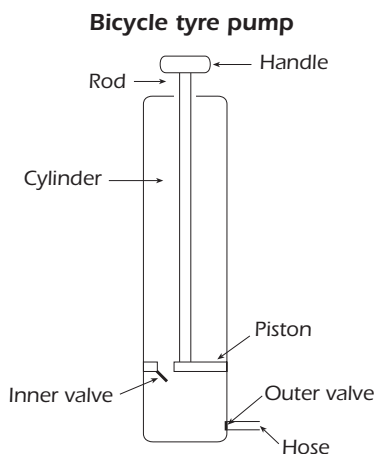


Problem Solving Unit 3

BICYCLE PUMP

Jane had some trouble with her bicycle tyre pump yesterday. She repeatedly pulled up and pushed down on the handle of the pump, but no air came out of the hose. She wanted to find out what was wrong, so she looked in the box where the pump was kept and found a piece of paper with the following information on it.

When the handle-piston assembly is pulled up, air passes through the inner valve and fills the space between the piston and outer valve. When the handle-piston assembly is pushed down, the inner valve closes and the piston forces the air beneath the piston out through the outer valve.



Problem Solving Example 3.1

Explain how the movement of the valves enables the operation of the bicycle pump when the handle-piston assembly is in different positions.

Scoring

Full credit

Code 2: Answers that describe what happens with BOTH movements of the handle-piston assembly.

- When the handle-piston assembly is pushed down, the inner valve closes and the outer valve opens.

AND

- When the handle-piston assembly is pulled up, the inner valve opens and the outer valve closes.

Partial credit

Code 1: Answers that describe what happens with the movement of the handle-piston assembly in one direction only.

- When the handle-piston assembly is pushed down, the inner valve closes and the outer valve opens.

OR

- When the handle-piston assembly is pulled up, the inner valve opens and the outer valve closes.

No credit

Code 0: Other answers.



Problem Solving Example 3.2

Identify two possible reasons that would result in no air coming from the hose. Give an argument supporting the possibility of each of your reasons.

Scoring

Possible reasons and explanations:

- inner valve is stuck closed and thus no air can come into the cylinder beneath the piston;
- outer valve is stuck closed and does not allow air to get out of the hose;
- piston is worn and thus there is no compression to force air to the hose;
- there is a leak in the cylinder wall below the piston, defeating compression;
- there is a leak in the hose, allowing air to escape;
- no air intake to cylinder.

Full credit

Code 2: Answers that mention TWO reasons with explanations.

Partial credit

Code 1: Answers that mention only ONE reason with an explanation.

No credit

Code 0: Other answers.

Problem solving processes

The development of a framework for problem solving requires the processes involved in student work on problem solving to be identified. This is not easy, as the ways in which various individuals solve problems do not fit into a standard format. The processes proposed below are based on the cognitive analysis of the three problem types described earlier, guided by the work on problem solving and reasoning of cognitive psychologists (*e.g.*, Mayer & Wittrock, 1996; Bransford et al, 1999; Baxter & Glaser, 1997; Vosniadou & Ortony, 1989), as well as by the seminal work of Polya (1945). The model proposed consists of processes that provide an organisational structure for examining student work and organising the problem solving assessment tasks. Note that no assumption is made that these processes are either hierarchical or necessary for the solution of any particular problem. As individuals confront, structure, represent and solve problems in a dynamic, real-time fashion, they may move to a solution in a way that transcends the narrow linearity of the present model. Indeed, most of the information about the functioning of the human cognitive system now supports the view that it is a parallel rather than a linear information processing system.

- *Understanding the problem.* This includes how students understand a text, a diagram, a formula or a table and draw inferences from it; relate information from various sources; demonstrate understanding of relevant concepts; and use information from their background knowledge to understand the information given.



- *Characterising the problem.* This includes how students identify the variables in the problem and their interrelationships; decide which variables are relevant and irrelevant; construct hypotheses; and retrieve, organise, consider and critically evaluate contextual information.
- *Representing the problem.* This includes how students construct tabular, graphical, symbolic or verbal representations, or how they apply a given external representation to the solution of the problem; and how they shift between representational formats.
- *Solving the problem.* This includes making a decision (in the case of *decision making*); analysing a system or designing a system to meet certain goals (in the case of *system analysis and design*), or diagnosing and proposing a solution (in the case of *trouble shooting*).
- *Reflecting on the solution.* This includes how students examine their solutions and look for additional information or clarification; evaluate their solutions from different perspectives in an attempt to restructure the solutions and make them more socially or technically acceptable; and justify their solutions.
- *Communicating the problem solution.* This includes how students select appropriate media and representations to express and communicate their solutions to an outside audience.

Summary of problem types

The entries of Table 4.1 summarise the basic features of the three problem types in terms of the goal, the problem solving process involved and the source of increasing complexity associated with the problems.

Situations

The assessment of problem solving in OECD/PISA should require students to apply their knowledge and skills in some new way; to transfer their capacities from one setting to another; and to use their knowledge in handling *decision making*, *system analysis and design* and *trouble shooting* problems. As such, the cross-disciplinary problem solving work will, in many cases, approach the notion of “life skills”. The problems will usually be embedded in real-life settings associated with personal life, work and leisure, or community and society.

LOCATING PROBLEM SOLVING WITHIN PISA 2003

While reading, mathematics and science are three major content domains in every education system, they do not provide all of the skills students need in preparation for adult life. An examination of the entering knowledge and skills expected of citizens and members of the workforce in the 21st century indicates that these expectations are changing as rapidly as advances in technology. As various forms of technology have replaced forms of manual labour, new knowledge and skills have supplanted more traditional content as entry expectations to adult life and work. The OECD/PISA assessments must measure



Table 4.1 ■ Facets of problem solving types

	Decision making	System analysis and design	Trouble shooting
Goal	Choosing among alternatives under constraints	Identifying the relationships between parts of a system and/or designing a system to express the relationships between parts	Diagnosing and correcting a faulty or under-performing system or mechanism
Processes involved	Understanding a situation where there exist several alternatives and constraints and a specified task	Understanding the information that characterises a given system and requirements associated with a specified task	Understanding the main features of a system or mechanism and its malfunctioning, and the demands of a specific task
	Identifying relevant constraints	Identifying relevant parts of the system	Identifying causally related variables
	Representing the possible alternatives	Representing the relationships among parts of the system	Representing the functioning of the system
	Making a decision amongst alternatives	Analysing or designing a system that captures the relationships between the parts	Diagnosing the malfunctioning of the system and/or proposing a solution
	Checking and evaluating the decision	Checking and evaluating the analysis or the design of the system	Checking and evaluating the diagnosis and solution
	Communicating or justifying the decision	Communicating the analysis or justifying the proposed design	Communicating or justifying the diagnosis and the solution
	Possible sources of complexity	Number of constraints	Number of inter-related variables and nature of relationships
Number and type of representations used (verbal, pictorial, numerical)		Number and type of representations used (verbal, pictorial, numerical)	Number and type of representations used (verbal, pictorial, numerical)



students' capabilities to adapt to change and to solve problems that require emerging key competencies.

Key competencies

The development of lists of skills or key competencies has been a central goal of several OECD activities, most visibly in the DeSeCo Project (Rychen & Salganik, 2000). This work found that key competencies are multifunctional and multidimensional in nature, and allow one to traverse domains and deal with higher orders of mental complexity. Key competencies enable individuals to deal with complex situations in active and reflective ways. In particular, they assist individuals in moving from dualistic views of their surroundings or issues to vantage points that reveal multiple, and sometime conflicting, interpretations of contexts and events. As such, they call on multiple mental processes. Although not always part of the OECD/PISA assessments, the processes listed in the DeSeCo report include:

- recognising and analysing patterns, establishing analogies between experienced situations and new ones (*coping with complexity*);
- perceiving situations, discriminating between relevant and irrelevant features (*perceptive dimension*);
- choosing appropriate means to reach given ends, appreciating various possibilities offered, making judgements and applying them (*normative dimension*);
- developing social orientation, trusting other people, listening and understanding others' positions (*co-operative dimension*);
- making sense of what happens in life to oneself and others, seeing and describing the world and one's real and desirable place in it (*narrative dimension*).

An appraisal of these processes shows that problem solving, viewed as a cross-disciplinary activity, is at the heart of the key competencies. The recognition, abstraction, generalisation and evaluation of patterns and the development of associated plans of action based on these processes are a core part of what problem solving adds in educational, vocational and professional decision making. Perceiving situations within complex contexts, and delineating the relevant features and constraints, are central to analysing systems and structures and to developing plans of action to confront problems in all forms of human activity. Choosing appropriate means to reach specified or desired ends is what problem solving adds to confronting difficulties encountered in life or in one's work.

Problem solving in employment trends and skills demand

As today's 15-year-olds will enter the work force within ten years, it is important, in evaluating their preparedness for life, to identify characteristics of the labour market they will encounter. Studies and surveys of employment trends and related skill demands indicate significant changes have occurred in the labour market over the past 20 years (ILO, 1998; OECD, 2001b).



Rapid technological advances and globalisation in business and industry have resulted in increased demands for highly-skilled professionals and technicians. These demands, in turn, have resulted in calls for education reform, both in formal schooling and in workplace training. In the United States, the Secretary's Commission on Achieving Necessary Skills (SCANS) report (U.S. Department of Labor, 1991) proposed a way for schools to conceive of needed knowledge and skills beyond the traditional academic disciplines. The SCANS framework consists of a three-part foundation accompanied by five general competencies (Stern, 1999). The skills foundation consists of:

- *basic skills*: reading, writing, arithmetic and mathematics, listening and speaking;
- *thinking skills*: creative thinking, decision making, problem solving, seeing things in the mind's eye, knowing how to learn and reasoning;
- *personal qualities*: responsibility, self-esteem, sociability, self-management and integrity/honesty.

The associated competencies include:

- *resources*: managing time, money, materials, facilities and human resources;
- *interpersonal*: participating on teams, assisting in teaching others, serving clients/customers, exercising leadership, negotiating and working with diversity;
- *information*: acquiring and evaluating, organising and maintaining, interpreting and communicating and using computers to process information;
- *systems*: understanding systems, monitoring and correcting performance, and improving or designing systems;
- *technology*: selecting technology, applying technology to tasks, and maintaining and troubleshooting equipment.

Thus, while the major academic subjects of reading, writing and mathematics are prominent in the SCANS basic skills strand, the developers of the SCANS report, like those of the DeSeCo report, have separated out problem solving and critical reasoning skills as a separate domain of study. This does not indicate a lack of problem solving activity or critical thinking in reading, mathematics and science. What it indicates is that there is an emerging and widespread belief that problem solving stands as a separate and well-recognised domain of human activity that is separate from the contributions of the disciplinary domains.

The SCANS and DeSeCo reports are but two examples of analyses of the knowledge and skills demanded by current and emerging conceptions of work force needs. Numerous other analyses have also provided similar pictures of the generic and work-related skills today's students will need. McCurry (2002) has provided an analysis of such reports. It shows that, apart from the knowledge and skills associated with traditional academic domains, problem solving or general thinking skills is an identified core competency for life and work in the world of tomorrow.



Contrasting PISA problem solving with the literacy domains

The assessment of cross-disciplinary problem solving in PISA 2003 differs from studies of problem solving in the three PISA literacy assessments and in extant psychological studies in several important respects. First, in OECD/PISA assessments of reading, mathematical and scientific literacy, problem solving is used to assess knowledge and understanding in the individual domains, while in OECD/PISA problem solving, the emphasis is on problem solving processes themselves. Secondly, OECD/PISA problem solving differs from the assessments in the literacy domains in that it emphasises the integration of information from different discipline areas, rather than drawing mainly on one domain of knowledge. Finally, the OECD/PISA assessments are different in the openness of their solutions and the complexity of the critical reasoning skills involved.

In its attempt to measure problem solving, the OECD/PISA assessment shares the project approach and focus on analytic reasoning with the International Survey of Adults (ISA) and some portions of the German national option from PISA 2000. On the other hand, the OECD/PISA assessment focuses on only three defined problem types, allowing for a clearer and deeper assessment of certain processes that students employ in these approaches. Perhaps most importantly, OECD/PISA differs from other large-scale educational assessment studies in that it is not curriculum based. Rather, OECD/PISA sets out to assess 15-year-old students' preparedness for life. As such, while the reading, mathematics and science frameworks all stress the literacy viewpoint and specify the roles that key concepts and skills in these domains play in preparing students for adult life, OECD/PISA problem solving focuses on the generic problem solving and reasoning skills that transcend academic domains.

Assessing processes rather than knowledge

As OECD/PISA problem solving focuses on generic reasoning and problem solving processes, it is important to recognise that problem solving is not a subject matter domain. Rather, problem solving is about the application of the processes people use in confronting problem situations (NCTM, 2000). Thus, OECD/PISA problem solving examines student work by concentrating on how students come to:

- understand the nature of a problem;
- characterise the problem by identifying variables and relationships inherent in the problem;
- select and adjust representations of the problem;
- solve the problem;
- reflect on the solution of a problem;
- communicate the solution of a problem.

Focusing on these processes rather than simply on final solutions permits an understanding of how people approach solving problems. Mayer (1985) notes that this information-processing approach to examining problem solving is



based on task analysis. As such, it provides an independent description of what problem solving contributes beyond just a score on a test. Understanding the processes involved can also help teachers to prepare instructional activities in teaching problem solving.

Problem solving types

As noted earlier, the three problem types used in the PISA 2003 assessment are *decision making*, *system analysis and design*, and *trouble shooting*. These problem types fit in well with both the SCANS and DeSeCo recommendations. The main reason for restricting the number of problem solving types is the limited time available for the assessment of problem solving. While it would be possible to select problem solving tasks from an extremely broad range of task demands, to identify likely strategies and to develop related contexts for setting the problems it was decided to limit the types and demands of the problems studied.

Within the three PISA problem solving types, many tasks involve problems dealing with scheduling, allocating resources, tracing the causes of problems, evaluating and organising information, and finding best options. While none of the tasks involves in-depth knowledge of reading, mathematics and science, they all involve logical thinking and analytical reasoning. These tasks do not belong to the reading, mathematics or science domains, but rather focus on the important foundational problem solving skills identified by the reports summarised earlier.

In order to adequately measure the cross-disciplinary aspects of problem solving, it is important that:

- the assessment focuses as heavily on the processes students use in solving problems as it does on the correctness of the solutions offered;
- domain-specific problem solving competencies related to the OECD/PISA literacy domains are included in the expectations, but that the problems employed to assess problem solving as a cross-disciplinary competency generally reach beyond a single domain by making connections to both non-subject area aspects of the curricular fields and by crossing subject matter curricular boundaries;
- cross-disciplinary problem solving competencies should be assessed by tasks that extend subject area measures in terms of content (focusing on real-life situations calling for transfer of curricular learning) and setting (focusing on complex, dynamic, real-life environments as well as reasoning tasks).

It is clear that cross-disciplinary problem solving forms an integral part of the skills demand for the current and future workforce and that the OECD/PISA problem solving component fills some gaps in assessing students' preparedness for life over and above the more academic domains. The current problem solving framework does not, however, cover all areas of problem solving: for example, interpersonal and group problem solving are regarded as important by many employers.



ASSESSMENT CHARACTERISTICS

Accessibility and equity

The assessment should be accessible to students regardless of the educational programmes in the participating countries. This means that the item can be understood and addressed by 15-year-old students regardless of the curriculum in which they are enrolled. Items should be developed in different representational modes (graph, table, words, symbols, pictures, etc.) that are easily interpretable by *all* students. Further, it is assumed that care will be taken that other sources of bias are avoided in the design and construction of the items. For example, excessively technical vocabulary, difficult reading level/vocabulary and items calling for specific personal life experiences should be avoided.

Calculators

An assessment of problem solving does not focus on students' ability to perform calculations. All students participating in the OECD/PISA problem solving assessment should therefore be allowed to use any hand calculators they routinely use in their classroom environments. The decision on whether or not to use calculators should rest with the individual students, based on their knowledge of when a calculator is appropriate and how it might add to the solution of a problem. No item should be constructed so that its solution is dependent solely on whether a calculator is used or not, or is of such a length that students not using a calculator would be severely disadvantaged in performing any calculations required.

ITEM TYPES

In previous large-scale assessments of problem solving, the types of items used have been multiple-choice, true-false or short response. These item types were used because they were viewed as contributing to higher reliability, providing more objectivity, reducing scoring costs and easing administration requirements when compared to assessments involving student constructed responses. However, to adequately ascertain students' abilities to reason, solve problems and communicate the results of such activities, more extensive records of their work are needed. Further, to adequately measure and describe students' work, it is important to be able to examine a variety of types of students' thinking in problem-related settings. Hence, a wider variety of item types is needed for the PISA 2003 cross-disciplinary problem solving assessment. In addition to multiple-choice items, the assessment will contain both closed and open constructed-response items. Each of these item types is described below.

Multiple-choice items

Multiple-choice items are appropriate for quickly and inexpensively determining whether students have mastered certain skills, knowledge or information gathering abilities. Well-designed multiple-choice items can measure student knowledge and



understanding, as well as students' selection and application of problem solving strategies. They can be designed to reach beyond the ability of students to “plug-in” alternatives or eliminate choices to determine a correct answer. However, multiple-choice items are somewhat limited in their ability to ascertain the full breadth and depth of a student's problem solving capabilities in many contexts.

Multiple-choice items in the OECD/PISA problem solving assessment should:

- not be answerable by simply plugging in values or by estimating measurements or size comparisons in the graphics supplied by the item;
- have distracters/alternatives designed to ascertain how students do or do not cope with a situation proposed in an item and to provide information about their thought processes, not to trick them into common error patterns;
- be used when an alternative item type would require students to draw a graph or construct a figure that would be complicated or time-consuming.

Closed constructed-response items

Closed constructed-response items allow examiners to assess higher-order goals and more complex processes in a controlled response format. Closed constructed-response items are similar to multiple-choice items, but students are asked to produce a response that can be easily judged to be either correct or incorrect. Guessing is less of a concern with closed constructed-response items, and they allow examiners to see what students can produce in a setting that does not call for “expert” marking and where partial credit is not an issue.

Closed constructed-response items on the OECD/PISA problem solving assessment should:

- be used when it is important to see that students can produce the answer to the item on their own;
- state explicitly what students need to do in responding;
- involve a limited range of responses in order that they can be quickly marked with a high degree of reliability.

Open constructed-response items

Open constructed-response items allow examiners to ascertain what students can produce based on their own understanding of an item and what students can communicate about how they solved the item. Short open constructed-response items require students to give brief answers: numerical results, the correct name or classification for a group of objects, an example of a given concept, etc.

Short open constructed-response items on the OECD/PISA problem solving assessment should:

- be used when it is important to see that students can produce the answer to the item on their own;



- state explicitly what students need to do in responding;
- allow examination of the degree to which students understand the problem.

Long open constructed-response items require students to show more complete evidence of their work or to show that they have used more complex thought processes in solving a problem. In either case, students are expected to clearly communicate their decision-making processes in the context of the problem (*e.g.*, through writing, pictures, diagrams, or well-ordered steps).

Open constructed-response items on the OECD/PISA problem solving assessment should:

- ask students to show integration of information or concepts, along with the way in which these lead to the solution of the problem proposed;
- tap multiple areas of understanding and require their connection in the students' responses.
- be used when the situation requires multiple steps to a solution and has several different components;
- require students to explain or justify the work produced;
- be amenable to rubric scoring in order that trained markers can mark the items efficiently and reliably.

Groups or units of items

In order to support a student's deep engagement with some problems (and possibly combat response motivation difficulties), the majority of items in the problem solving assessment should be developed in groups or units, about themes or project-based situations. Such units should contain collections of two or more items, often involving different representations or measured by different item types, which are related either by a shared topic focus or by a common context. In either instance, the items in the units should be independent, at least to the extent that a correct answer to one item in the set is not required in order to get a subsequent item correct.

Marking guides

Marking guides or rubrics for evaluating student responses to items should be constructed within a general framework that values the major aspects of problem solving. Such rubrics should allow the recognition of student work attaining the levels of:

- understanding the information given;
- identifying or characterising the critical features and their interrelationships;
- constructing or applying a representation of the problem;
- solving the problem;
- checking, evaluating or justifying aspects of the problem;
- communicating the problem solution.



In such rubrics, the highest level of scoring should reflect a complete understanding of the problem, require a correct solution, reward thought that shows considerable insight, and reflect work that is clear, appropriate and fully developed. Such responses should be logically sound, clearly written and contain no errors. Any examples given should be well chosen and fully developed.

At a slightly lower score level, one might encounter work that demonstrates a clear understanding of the problem, shows some insight and provides an acceptable approach, but still contains minor weaknesses in its development. Examples are provided, but they may not be fully developed.

At an even lower level, one may see work that contains evidence of an understanding of the problem at a conceptual level, evidenced by the logical approach taken or representation chosen. However, on the whole, such a response is not well developed. While there may be serious logical errors or flaws in the reasoning, the response does contain some correct work. The examples provided may be incorrect or incomplete.

Finally, there would be a no credit level for coding completely incorrect or irrelevant responses. Within the scoring at this level, some allowance should be made for distinguishing between students who attempt a given problem and those who submit a blank response. The latter may signal either lack of time or a motivational problem.

It should be noted that not every item will elicit all of the three positive credit levels described above, but collectively for the problem solving test, there will be items tapping into different levels of student performance.

Double-digit scoring

In addition to scoring the student responses for correctness, the marking guides or rubrics should provide a basis for scoring the items for the strategies employed by students in solving a given problem, or for showing the misconceptions that prevented students from reaching a correct solution. This form of scoring is useful in attempting to grasp the nature of student thinking and the degree to which students have some command of higher-order thinking skills. Such scoring can be accomplished via the use of the dual coding scoring methods used in both the TIMSS and PISA 2000 assessments. This approach employs a two-digit code in scoring the items. The first digit of the code indicates whether the student receives (full or partial) credit, provided incorrect work, wrote unintelligible work or left the response area blank. The second digit of the code provides information on the type of approach that the student used if the item was worked correctly. If the student did not receive any credit, the second digit could provide information on the error patterns or misconceptions that characterise the student work.

General structure of the assessment

The cross-disciplinary problem solving assessment will consist of two 30-minute clusters of units of items. The three problem types (*decision making*, *system*



analysis and design, and *trouble shooting*) are represented, respectively, in the ratio of 2:2:1.

Each cluster has items grouped into four or five different units. There are about 50 per cent single marker items (multiple-choice and closed constructed-response items) and about 50 per cent items requiring multiple markers (open constructed-response items). Each unit should have at least one item that requires students to solve or evaluate a solution strategy for the focus problem of the unit.

The degree of explicitness of the information for the tasks can vary. Some tasks may contain pre-structured information with given constraints, while other tasks may require students to extract information and build the constraints themselves.

Where appropriate, the “problem” or task for students should be clearly stated at the beginning of each item. Each unit should have an introduction clearly stating what kind of tasks students are required to do and what evidence students need to provide.

In any given unit, there should be no more than three source materials to avoid confusion for the students, but generally more than one discipline’s information base should be called upon within any unit.

ANALYSES AND REPORTING

One scale will be developed to report the outcomes of the cross-disciplinary problem solving assessment, separate from those being developed for the other major and minor domains of PISA 2003.

The report of the cross-disciplinary assessment of problem solving will be designed to provide policy makers, administrators, teachers, parents and students with a clear picture of students’ competencies in problem solving. In particular the reports of results should provide:

- a proficiency scale with accompanying text explaining the nature of students’ problem solving capabilities at various points along the scale;
- item maps similar to those used in other OECD/PISA domains to discuss the relative difficulty of item types and to compare student capabilities across items, contexts and other design features;
- data on the relationships existing between students’ problem solving performances and performances in other areas of the OECD/PISA assessments;
- special reports that reflect the performance of specific subgroups of students – those of different genders, SES or curricular tracks.

POTENTIAL EXTENSIONS OF THE FRAMEWORK FOR FUTURE OECD/PISA CYCLES

Two options should be considered for future cross-disciplinary problem solving assessments in OECD/PISA. These options involve the assessment of



collaborative problem solving, and the use of computer-delivered assessments designed along the lines of the work of Klieme and his colleagues (in press).

Collaborative problem solving

A collaborative problem solving option might consist of a separate block of items students would complete in groups of three. Items in such blocks could be built from items in the regular cross-disciplinary assessment. This would allow for a comparison of students' work in individual settings with their work in collaborative settings. Such assessment blocks would have to allow time for idea generation and formulation and for the development of group roles on the part of the students involved.

The *Pacesetter* programmes of the College Board (2000) have working models of such assessments of collaborative problem solving. Expectations of student competence in problem solving and in education in general require the development of these competencies in an environment that values social or collaborative learning. In that case, they must also be assessed. Given the relation of collaborative problem solving to country-specific goals for students, such an assessment might be developed as an international option within the OECD/PISA cross-disciplinary problem solving assessment in future cycles.

Computer-based delivery

International interest in students' real-time problem solving capabilities in dynamic settings calls for the development of assessment options that would allow for computer-delivered assessments along the lines described by Klieme (2000). Such assessments provide a rich display of students' problem solving competencies in a dynamic environment. They also allow an examination of how students order and conduct their work in complex settings in a way that no paper-and-pencil based assessment can provide. Such an approach allows for the study of the interaction of pieces of information with the selection of problem solving strategies and the formulation of problem solutions. As with the assessment of collaborative problem solving, the provision of computer-based assessment problems should be considered as an international option in future studies.

ADDITIONAL EXAMPLES

The following units illustrate a range of units, items, and tasks found in the OECD/PISA cross-disciplinary problem solving assessment. These units were used in the field trials for PISA 2003, but not selected for use for one reason or another. However, all deficiencies noted have been repaired, unless otherwise indicated, and these units are offered here as examples of what the units and items in the assessment are like. Since the PISA 2003 assessment was not completed when this publication went to press, no items from that assessment are included here for reasons of test security.

The three units presented here complement the three problem solving units previously presented (Problem Solving Units 1, 2 and 3). These six units provide



a fairly complete picture of the variety of problem solving situations in the PISA 2003 problem solving assessment. There are two *decision making* units, two *system analysis and design* units (one on analysis and one on design), and two *trouble shooting* units (one in the context of systems and one using the context of a mechanism). The various items in the units reflect the full range of item formats and response requirements.

The items in the units are presented in boxes with some explanatory comments and notes to illustrate what was expected and what typical student responses were in the field trials. After each unit's items, the marking guide for the unit is presented.



Problem Solving Unit 4

BATTERIES

Problem Solving Unit 4 presents students with a problem context that involves deciding how to determine which brand of batteries is the best to buy to power a personal stereo. Vania has asked four friends to join her in an experiment in which each will try two brands of batteries and then record the length of time each brand powered their individual stereos. The data from Vania and her friends is then provided in tabular form for the students to use in responding to the two items in this unit.

This problem is about deciding which are the best batteries to buy.

Vania notices that some brands of batteries she uses in her personal stereo seem to last longer than others. There are four different brands she can buy that fit her personal stereo. She asks some of her friends to help her decide which is the best brand of battery.

Each of her friends tries two brands of battery in their personal stereos. Figure 1 shows what they tell her. (They use one brand until it runs out and then use another brand until it runs out.) All the batteries have the same voltage rating.

Figure 1 How Long Different Brands of Batteries Lasted

	First brand of battery tried	How long it lasted	Second brand of battery tried	How long it lasted
Vania	N-dure	5 days	Powerpak	5 days
Mark	X-cell	4 days	Hardcell	5 days
Kiki	Powerpak	6 days	Hardcell	5 days
Paul	Hardcell	3 days	N-dure	4 days
Elizabeth	N-dure	7 days	X-cell	4 days

Problem Solving Example 4.1

Vania looks at the results of her investigation and says, "This investigation shows that Powerpak lasts the longest."

Give a reason, based on the results of the investigation, why you could conclude that "Powerpak lasts the longest."



Scoring and comments on Problem Solving Example 4.1

Full Credit

Code 1: • Answers that mention that Powerpak lasts the highest average length of time - $(6+5)/2 = 5.5$. All other battery types have lower averages (N-dure = 5.33, X-cell = 4, Hardcell = 4.33).

Note: The calculations do not need to be shown for the award of the mark.

OR

• Powerpak lasted 5 days or more. All other types have a lower minimum (4, 4, and 3 days).

No Credit

Code 0: Other answers.

Item type: Open constructed-response

Problem solving type: Decision making

Situation: Personal life/Scientific

.....
This item calls on students to comprehend the nature of testing a product such as batteries and the role that data might play in such a test. Given the data in the table, it appears that some form of comparison of the life of the batteries is a possible response plan. To do so, students are required to recognize that they are being asked to create a comparison and provide some form of justification for their response.

If students approach the item by finding the average battery life and then concluding that Powerpak batteries have the longest life, since their average life is the greatest, then they have examined information, compared alternatives, formed a generalisation, and communicated their results.

Some students failed to grasp what they were asked to do. They interpreted the item as asking for an explanation of the power demands of students' stereos or focused only on the first or second battery tested by the individual students. Some students gave reasons unrelated to the investigation, such as "You can tell from the TV advertisements".

This item may be somewhat similar to an item students may see in consumer economics. For most students, however, this item will be a non-routine item and one that will cause them to think in new ways and form a communication describing their findings.

Problem Solving Example 4.2

Give TWO different reasons why the results of this test may not be reliable.



Scoring and comments on Problem Solving Example 4.2

Possible reasons:

- usage on each day is unspecified in terms of time and purpose (playing, rewinding, volume, etc.);
- the investigation involves a small sample;
- the measurements are crude – what is meant by a “day”?
- the fact that sometimes a battery of the same sort lasts seven days and sometimes four days means that the results are likely to be suspect;
- different stereos may have different power requirements.

Full Credit

Code 2: Answers that mention TWO possible reasons very clearly, from the above list.

Note: the two reasons should be different, and not merely two ways of saying the same thing.

Partial Credit

Code 1: Answers that mention only ONE possible reason very clearly, from the above list.

No Credit

Code 0: Other answers.

Item type: Open constructed-response

Problem solving type: Decision making

Situation: Personal life/Scientific

.....

This item calls for students to examine the constraints under which the experiment took place, to note the factors that were possible sources of variation in the life of the batteries, and to examine alternative explanations for the test outcomes.

Some students failed to understand the task and tried to explain why the result noted in Problem Solving Example 4.1 is really true. Other students focused on a particular facet of the situation and gave only one reason, or two equivalent reasons, why the test results may not be reliable. For example, one student’s two reasons were that some stereos may have been switched off and on and that the stereos may not have been played for the same amount of time.

Success in responding to this item requires students to have a solid comprehension of the task of testing the life of a battery. This involves being able to list possible factors related to the life of a battery, to examine the interrelationships among these factors, to compare and contrast these factors with those used in responding to Problem Solving Example 4.1 above, and to carefully communicate two alternative explanations that would discredit the response formed by Vania.

The ability to correctly answer this item may be related to students’ experience with the scientific method. For this reason, this unit was not included in the main study but saved for use as a sample unit.



Problem Solving Unit 5

ROLLERS

Problem Solving Unit 5 presents students with two problem contexts that deal with analysing how a system of rollers turns and then a context in which they must design a drive belt system that will turn a set of rollers in specified directions.

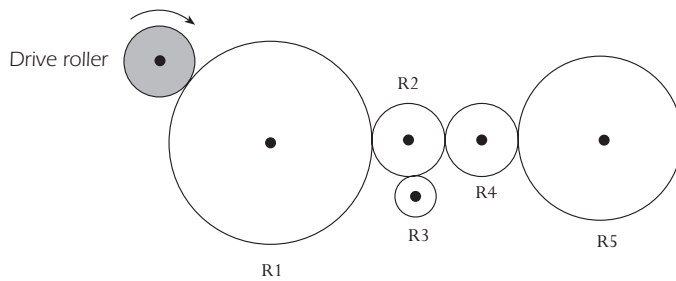
The introductory material presents a simple roller system and provides figural information about how the rollers in the system rotate, given the direction of the drive roller.

This problem is about designing a set of rollers to turn in a particular way.

A set of rollers can be made to turn by placing the rollers in contact and then turning one of the rollers. The roller turned is called the **drive roller**.

Problem Solving Example 5.1

Here is an arrangement of rollers.



Which roller(s) will turn in the same direction as the drive roller, and which will turn in the opposite direction?

ROLLER	WILL IT TURN IN THE SAME DIRECTION AS THE DRIVE ROLLER OR IN THE OPPOSITE DIRECTION?
R1	Same direction / Opposite direction
R2	Same direction / Opposite direction
R3	Same direction / Opposite direction
R4	Same direction / Opposite direction
R5	Same direction / Opposite direction



Scoring and comments on Problem Solving Example 5.1

Full Credit

Code 1: Answers that specify Opposite, Same, Opposite, Opposite, Same, in that order. (R2 and R5 will turn in the same direction as the drive roller.)

No Credit

Code 0: Any other combination of answers.

Item type: Complex multiple-choice

Problem solving type: System analysis and design

Situation: Personal life/Work and leisure

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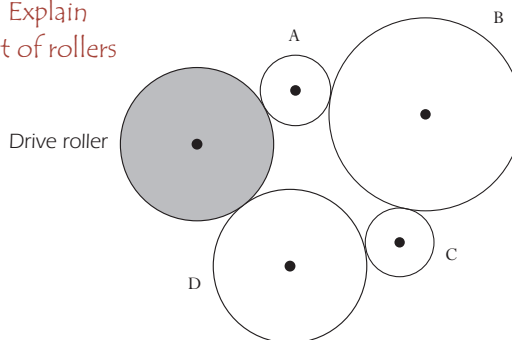
To correctly respond to this item, students must understand the relationship among rollers and how movement takes place in sequential rollers as a result of a movement of the drive roller. Such thought on the part of students calls for them to induce a rule about roller rotation direction based on the example, and perhaps on their understanding of the relationship between successive rollers in similar, familiar settings.

Based on their intuitive understanding of the situation, students then form a generalisation that says, in some form, that successive touching rollers move in opposite directions. This generalisation alone is not sufficient to completely respond to the question asked. Students also have to see this relationship as a transitive relationship: that if A-B-C is a chain of touching rollers, then if A moves clockwise, B moves counter-clockwise, and C again moves clockwise. This transitive understanding allows students to move the explanation through a sequence of successive rollers, perhaps by adding arrows that alternate between clockwise and counter-clockwise from one roller to the next. This understanding is also analogical in nature.

Students' developed abilities to answer the items in this unit are based, in part, on their understanding of mechanical systems and their spatial reasoning. For this reason, this unit was not included in the main study but saved for use as a sample unit.

Problem Solving Example 5.2

Some arrangements of rollers will not turn when the drive roller is turned. Explain why the following arrangement of rollers will not turn.





Scoring and comments on Problem Solving Example 5.2

Full Credit

Code 1: Answers that mention that if the drive roller turns clockwise, A will go counter-clockwise, B will go clockwise, C will go counter-clockwise, D will go clockwise, and force the drive roller to go counter-clockwise. Since it is already turning clockwise, movement is not possible.

OR

Answers that mention equivalent statements (check student's markings on the diagram in conjunction with the texts they write.):

- because each roller will be “pushed” in one direction by one roller and in the opposite direction by the other roller with which it is in contact;
- because the drive roller and one of the rollers next to it will be trying to turn in the same direction;
- they will clash, *e.g.*, B and C will want to move in the same direction;
- roller A is turning roller B in a different direction from roller C, so it will not turn.

No Credit

Code 0: Other answers, for example:

- because they are linked, and not in a straight line;
- because they are not joined;
- because they are all going in opposite directions.

Item type: Open constructed-response

Problem solving type: System analysis and design

Situation: Personal life/ Work and leisure

Like Problem Solving Example 5.1, this item calls on students' comprehension of the relationships among a sequential set of rollers and the ability to transfer this understanding across the many successive sets of rollers in this “ring”.

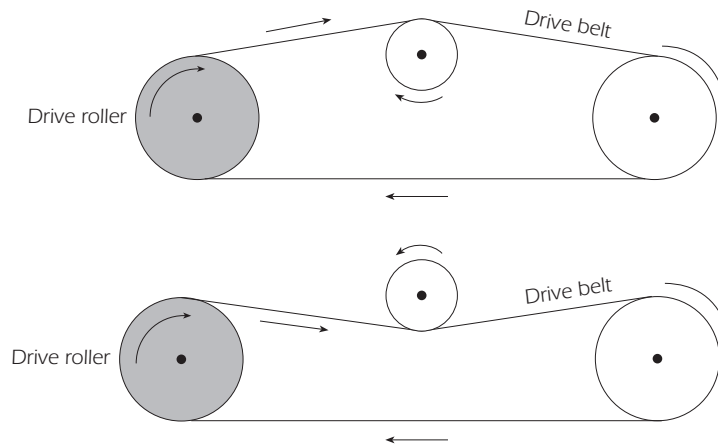
Here students have to put their induced rule concerning the alternating rotation of sequential rollers to the test. This is an act of system analysis. This item calls on students to check specific cases in a particular problem context for consistency with respect to the rule they have formed concerning the rotational behaviour of rollers in a spatially arranged system.

The reasoning in this item is new to many students. Few students have experience in attacking a spatially defined situation and looking for evidence that a particular outcome is not occurring. Analysing a system to find out non-performance is different from most similar school exercises. The “explanations” of many students consisted only of arrows indicating that there was eventually a clash of rotational direction as you moved around the system.

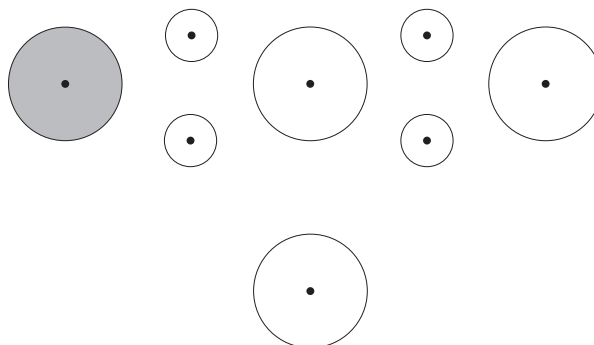


Problem Solving Example 5.3

Another way a set of rollers can be made to turn is by using a drive belt which connects the drive roller to the other rollers. Here are two examples:



Draw a drive belt around this set of rollers so that all the large rollers turn clockwise and all the small rollers turn anti-clockwise. The belt must not cross over itself.

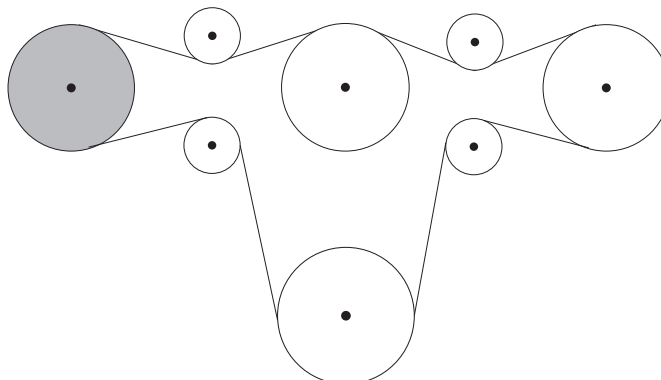


Scoring and comments on Problem Solving Example 5.3

Full Credit

Code 1: Answers that follow the example below.

Note that Code 1 should be awarded even if the belt in the drawing does not actually touch the rollers.





No Credit

Code 0: Other answers.

Item type: Open constructed-response

Problem solving type: System analysis and design

Situation: Personal life / Work and leisure

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This item involves comprehending the operation of rollers relative to the motion of the drive roller and the contacts between other rollers and the drive belt. In this case, students must induce a rule about the operation of the drive belt and the rotation of the rollers according to whether or not they are on the same side of the drive belt or on opposite sides.

Once students have induced this relationship, they have to check it and then form a design (in this case the placement of the drive belt on the set of rollers provided) and to “build the system” that will carry out the desired rotational effects in the roller set. When students have built their design, they need to check it again to ensure that it creates the desired rotations in the rollers.

This problem has more than one correct solution but “non-symmetric” designs were hardly ever given as student responses.

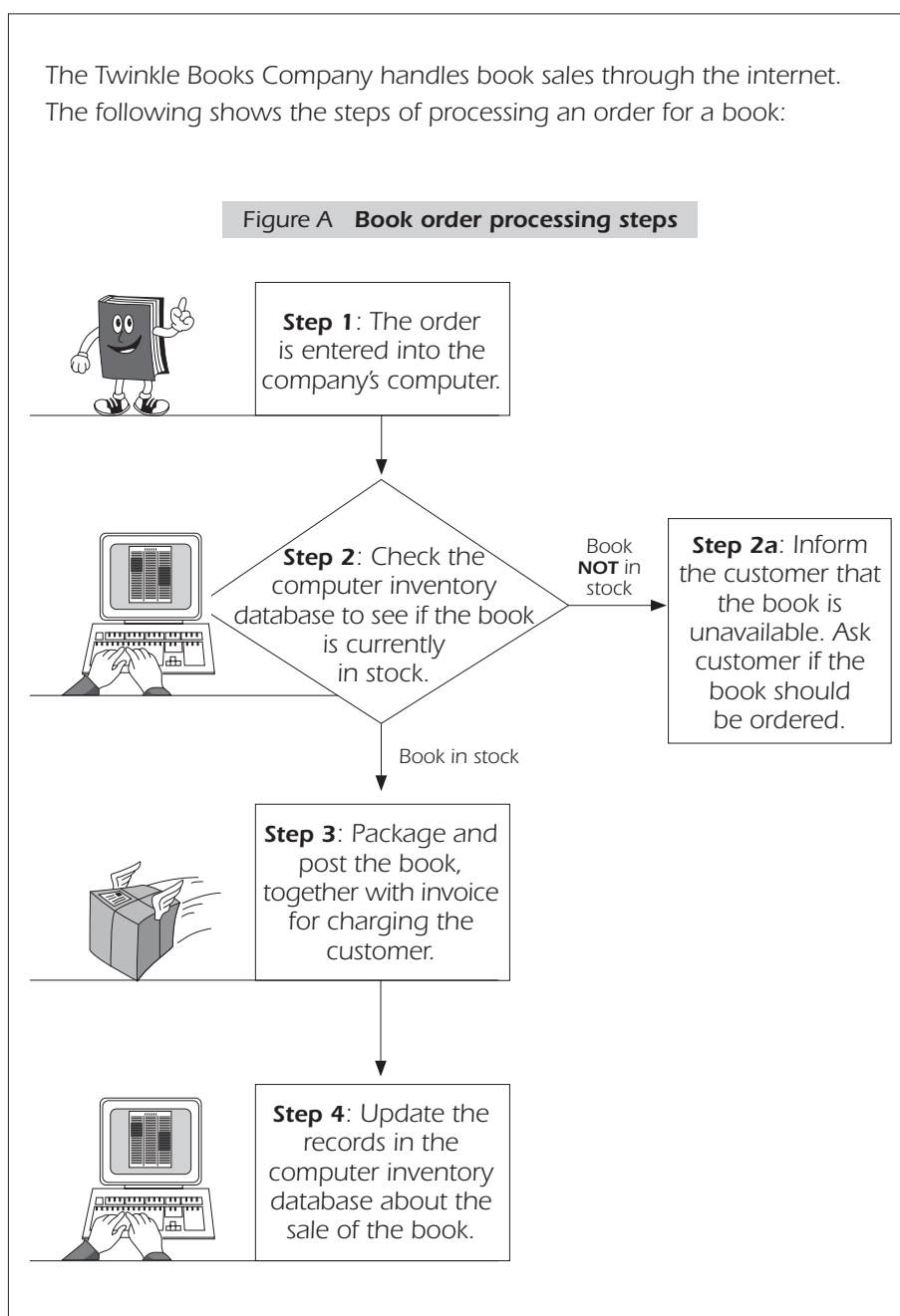


Problem Solving Unit 6

BOOK SALES

Problem Solving Unit 6 presents students with a problem context that concerns a book company's internet ordering system. The problem involves analysing the book ordering system, trouble shooting where customer address problems might occur, and altering the ordering program to insert a given subprocess that verifies and charges the customer's credit card account.

The unit begins with the presentation of a flow-chart that shows the steps involved in processing a book order placed with the company over the internet.





Problem Solving Example 6.1

A book sent to a customer was returned because of an incorrect address. In which step(s) of the process could the error have occurred?

Step	Could the error have occurred in this step?
1	Yes / No
2	Yes / No
2a	Yes / No
3	Yes / No
4	Yes / No

Scoring and comments on Problem Solving Example 6.1

Full Credit

Code 1: Answers that specify Yes, No, No, Yes, No, in that order.

No Credit

Code 0: Any other combination of answers.

Item type: Complex multiple-choice

Problem solving type: Trouble shooting

Situation: Work and leisure

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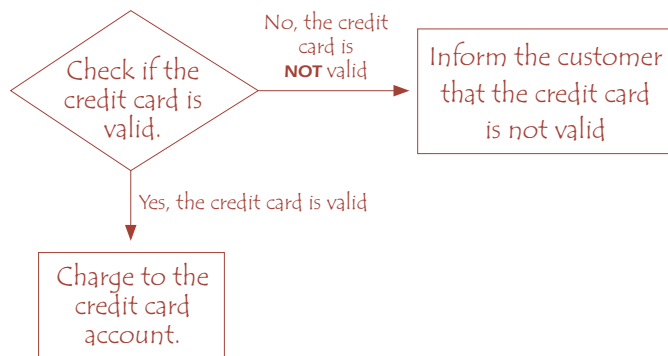
A correct response to Problem Solving Example 6.1 requires students to understand the relationships between the various steps of the procedure, and the directions associated with each one. Understanding such a procedural diagram is crucial to the analysis and trouble shooting of many sequentially designed business procedures, where the temporal aspects of decision making are central to carrying out a procedure such as the present one.

Once students have analysed the procedure, they must diagnose the specific problem presented in the item. In this case, the process involves performing a large number of tests involving conditional reasoning of the form “If this type of error occurs here, then how does it affect the mailing of a package or letter further along in the system?”. To correctly carry out the needed trouble shooting steps, the student must be able to reason in settings involving both verbal and diagrammatic information.

Problem Solving Example 6.2

The Twinkle Books Company is having difficulty in getting some customers to pay for their books. As a result, the company wants to require customers to give their credit card number when they order a book.

To do this, the company wants to add the following steps to the process in Figure A.



Where in Figure A should you insert the above steps for checking and processing credit card information?

- A. Between steps 1 and 2.
- B. Between steps 2 and 3.
- C. Between steps 2 and 2a.
- D. Between steps 3 and 4.
- E. After step 4.

Scoring and comments on Problem Solving Example 6.2

Full Credit

Code 1: Response B: Between steps 2 and 3.

Note: The debiting of the charges should not occur until the company is sure that it can deliver the product to the customer.

No Credit

Code 0: Other responses.

Item type: Multiple-choice

Problem solving type: Trouble shooting

Situation: Work and leisure

Like Problem Solving Example 6.1, this item requires students to reason from verbal and diagrammatic information to understand sequential aspects of the procedure. However, in addition, in this item the student must design a system by locating, via a careful analysis of the logic involved, where to insert a given subprocess that checks *and charges* a customer's credit card as part of the ordering procedure. Locating the subprocess correctly (*i.e.* between steps 2 and 3) depends on recognising that the customer should not be charged unless the book is in stock.

Many students chose option A (between steps 1 and 2), which may correspond to the practice of some companies. For this reason, and the fact that experience with internet ordering could vary widely among students, this unit was not included in the main study but saved for use as a sample unit. ┘