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ABSTRACT

Using Guttman's facet design analysis, four parallel forms of a multiple-choice test were developed. A mapping sentence, logically representing the universe of content of a basic cardiology course, specified the facets of the course and the semantic structural units linking them. The facets were: cognitive processes, disease priority, specific disease, and clinical judgment stage. Developing items from specification strings was simpler and quicker than developing items from objectives without specific guidelines. Due to logistical problems, only two of the four parallel forms originally planned were actually used. Although this increased the number of times each item was used, it did not violate the theoretical methodology, nor the notion that the tests were parallel. The tests will be field tested with fourth-year medical students at five medical schools, to establish their parallel forms reliability. (CP)

A PRACTICAL METHODOLOGY FOR THE SYSTEMATIC DEVELOPMENT OF EQUIVALENT MULTIPLE-CHOICE TESTS

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A Practical Methodology for the Systematic Development of Equivalent Multiple-Choice Tests

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This paper discusses how parallel multiple-choice question tests were developed using Guttman's facet design analysis. Facet design analysis provides a logical link between the instructional content and the items because the items are specified by the facet analysis of the objectives. A mapping sentence was developed from the facet analysis which defined the universe to be tested. This mapping sentence was used to specify a test blueprint for the parallel exams and also specified the particular dimensions of each item. This paper shows how facet design analysis is a practical way to develop parallel exams.

A PRACTICAL METHODOLOGY FOR THE SYSTEMATIC DEVELOPMENT OF EQUIVALENT MULTIPLE-CHOICE TESTS

OBJECTIVES

The development of a detailed blueprint of an exam including the specifications of test content and the number of questions per content area is an important step in test development. When alternate forms of an examination are needed, test constructors most often use the process of developing a content-by-cognitive behavior matrix as a way of a priori insuring functionally equivalent tests. However, most test development reference books (e.g. Popham, 1975 and Thorndike, 1971) do not discuss rules for constructing these matrices or for selecting items. These matrices may be a product of the test developers concept structure and their own idiosyncracies. Often, sets of items have not been shown to be equivalent by any empirical method (Bormuth, 1970).

A number of new approaches have been proposed which attempt to define rules for generating items. These item-generated mechanisms provide for the construction of tests which are content valid in a logical as well as judgmental way (Millman, 1974 and Martuza, 1977). One of these new approaches, the facet design approach, is employed here to develop equivalent multiple-choice tests. The purpose of this paper is to illustrate a method of developing alternate forms of tests according to logical rules of equivalence of facet design analysis.

Theoretical Orientation

Facet design was developed by Guttman (1969) for the purpose of defining a research domain. Facet design specifies the limit of the domain as well as the ordering of all of the subcomponents of the domain. It is a powerful tool in defining a problem, structuring relationships within and among variables, and dealing with the problems of equivalence (Jordan, 1978). A system similar to a Cartesian coordinate system is used to specify the relationship of subcomponents of the domain. Instead of drawing the numerous coordinates on graph paper, a mapping sentence is constructed (Engel, 1975).

A mapping sentence provides an integrated system for defining the universe of relevant concepts. It is composed of two parts: the facets and the phrases linking the facets together. The facets are categories of relevant content. The phrases linking these categories suggest the semantic structural unity which integrate all of the facets together. Each facet is defined in terms of specific information which is presented in a list. A facet element is a particular example from the list of a relevant concept. Figure 1 shows a sample mapping sentence. Thus, a mapping sentence, through the use of facets and facet elements, analyzes the domain to be sampled into all of its relevant component parts (Millman, 1974, Martuza, 1977, and Shye, 1978).

<u>Insert Figure 1 About Here</u>

One specific element from each facet is combined to form a facet string. A facet string defines a particular segment of the universe. Theoretically, the number of possible facet strings is equal to the number of combinations of all the coordinates. However, some of these facet strings are null sets when real data are applied.

Millman (1974), Engel (1975), Martuza (1977), and Berk (1978) propose the use of facet-design analysis for test-item construction. Initially the test constructor conceptually analyzes the content to be tested by dividing the content into its component parts. The result of this analysis yields a mapping sentence of the universe. Specific items can be generated from facet string specifications.

After reviewing various techniques for test specifications and item-generation, Engel (1975) concluded that the facet-design approach is the only approach which is explicitly based on a meta-theory of content representativeness. This advantage of a theoretical base makes this approach fundamentally attractive since it is operational for constructing multiple-choice tests. Facet-design analysis provides a logical link between the instructional content and the multiple-choice items because the items are specified by the facet-design which follows from the objectives. Unless a theoretically based methodology such as facet design is used, there is no a priori way of justifying the necessary assertion that the items included in the parallel forms define the same kind of behaviors. By constructing test specifications and items on the basis of a facet analysis, it becomes possible, in principle, to devise parallel forms in terms of content.

Methodology

Task

A test specialist was asked to help cardiologists develop four parallel multiple-choice tests examining the content of a basic cardiology course as part of a larger research project. This project involved five medical schools. Each test was to be composed of about 100 items. First the cardiologists identified twenty-three diseases that were pertinent to the students' level of learning. Next, these diseases were ranked high, medium or low priority based on frequency of occurrence. The test specialist employed facet design analysis in order to insure content domain equivalence.

The test specialist studied the objectives and developed a mapping sentence which had four major facets and at least three elements within each facet. Figure 2 shows the mapping sentence used for the test specification and item development. The elements have been ordered on the following dimensions: Facet A - cognitive processes employed which are ordered according to an adaptation of Gagne's (1970) and Bloom's, et. al. (1956) cognitive hierarchies; Facet B - disease categories which are ranked from high to low priority in terms of the objectives; Facet C - specific diseases which are ordered alphabetically; and Facet D - the stages in clinical judgment which are ordered by the chronological sequence of clinical judgments.

Insert Figure 2 About Here

Theoretically, the next step would be to list all of the possible 2,592 facet strings. (There is a total of 39 different coordinates from four facets - 6 X 3 X 24 X 6.) This was an unrealistic step especially since many of the facet strings do not reflect reality. For example, the use of visual information such as x-rays or electrocardiograms only enter into selected steps such as data gathering (D_1), interpret laboratory data (D_3) and diagnose patient problems (D_4). While computer techniques are available to list the strings, it was decided that in this particular application, it would be sufficient to allow the content specialists to select the salient strings.

Test Specification

One cardiologist determined the overall blueprint for the exam. For example, he specified that about one-third of the items should test the student's ability to describe and interpret chest x-rays, electrocardiograms, phonocardiograms and echocardiograms (e.g., A_2 and A_4). From this general specification of the types of desired questions, the particular facet strings were selected which fulfilled these general criteria.

Each disease was ranked high, medium or low priority in the objectives. The test specifications stated the approximate number of items for each disease for the three ranked priorities. However, the particular disease was not specified in the test blueprint. Thus, Facet C, the name of the disease was incorporated into Facet B in the test specification facet string.

Table 1 shows the test specification blueprint defined in facet strings. The three facets used in test specification are: A. cognitive processes required, B. priorized diseases and D. the step within the clinical process. The number after each Facet letter refers to the specific element of the Facet as identified on Figure 2. Specification $A_1B_2D_4$ means that items should pertain to, "Recall of factual information relating to the diagnosing of patients with high priority diseases." This specification was used to generate two items. In order to insure that the four tests would be parallel in terms of content, one set of facet strings determined the test specification blueprint for all of the examinations.

The visual information referred to in Facet A_2- verbally describe visual information and Facet A_4- interpret visual information includes the use of the following diagnostic tests: ambulatory electrocardiographic monitoring (Holter monitoring), angiography cardiac catheterization, chest x-ray, cineangiogram-coronary-arteriography, echocardiogram, electrocardiogram, impulse tracing, phonocardiogram, radionuclide imaging (Mycardial-scanning), and treadmill stress test. The same diagnostic test used on one exam was used on the other three exams with that facet string. For example, since Exam A required students to interpret a chest x-ray during the data gathering phase from a patient with mitral stenosis, Exams B, C and D also required students to interpret chest x-rays during the data gathering phase from patients with high priority diseases.

Facets A, B, and D are used for test specification, whereas Facets A, C, and D are used for item specification. The rationale for the use of these facets is explained earlier.

<u>Insert Table 1 About Here</u>

Item Specification

It was assumed that at least one item could be written for each disease which fulfilled the criteria of a facet string in Table 1. For example, the facet string for the test specification "$A_1B_1D_1$" specified that the item should recall factual information relating to the data gathering step on a high priority disease. There were ten high priority diseases. Therefore, at least ten different items could be developed from this facet string since it was assumed that knowledge about the ten diseases are interchangeable. These ten items could be assigned to ten parallel examinations. Since only four parallel examinations were required, only four such items had to be developed. However, for the facet string "$A_1B_1D_1$" two items per examination were required because of the item specification developed (see Table 1). Thus, eight separate items had to be developed which required the recall of factual information pertaining to ordering laboratory tests for high priority diseases. Preferably these eight items would each deal with a separate high priority disease.

As indicated in the above paragraph, three facets (A, C, and D) were used for the item specification. Since all of the diseases were assigned a priority ranking, the priority facet (B) was not necessary when the individual diseases were considered in the actual item specification. The test specification facet string $A_1B_1D_1$ resulted in the following ten item specification facet strings since there were ten high priority diseases:

$A_1C_2D_1$	$A_1C_{10}D_1$
$A_1C_3D_1$	$A_1C_{12}D_1$
$A_1C_5D_1$	$A_1C_{13}D_1$
$A_1C_7D_1$	$A_1C_{14}D_1$
$A_1C_8D_1$	$A_1C_{15}D_1$

At least one item could be developed from each item specification facet string.

Item Development

The cardiologists had already begun to develop a pool of items. Only those items which met the test specification facet string requirements were selected for the pool. In some cases several items were in existence. Instead of rejecting good items, these parallel items were placed in the pool.

After the classification of the existing items it became clear that more items were needed to meet the exam specifications. The cardiologists were then asked to develop items according to the particular test specification facet strings that were lacking the required number of items as shown in Table 1. The item pool contained sets of items grouped according to the test specification facet strings from which they were derived.

Test Development

Since the cardiologists did not have the time to develop four hundred items, they asked the test specialist to recommend a way of developing useful exams using fewer items. After a discussion with one cardiologist, it was decided that 50% of each exam could have common items. Next the test specialist assigned items to each exam based upon the test specification table of facet strings (Table 1). Items were assigned randomly to one of four exams except with the stipulation that if more than one item was required for that facet string per exam, each item in an exam from that facet string would be concerned with a different disease. A running tally was kept on the items as they were assigned to exams in order to insure that there would be the correct number of items for each high, medium, and low priority disease. Frequently items had to be juggled from one exam to another. Yet, no matter how the items were juggled, all of the test specification criteria (e.g., Table 1 and the frequency of items per disease) could not be met with the existing pool. For example, on one exam there were too many items on normal patients and not enough items on aortic stenosis. Therefore, a cardiologist was asked to develop more items to be placed in specific slots on each exam on the basis of item specification facet strings. An item specification for each of the four parallel exams was developed. Table 2 shows the item specification for Exam A.

Insert Table 2 About Here

Test Use

The four exams were pilot tested. During the review process, it was decided that only two exams would be used due to logistical problems and problems with the difficulty or wording of specific items. The items on these two exams were derived from the original four parallel exams.

These exams will be used for fourth-year medical students in a cardiology rotation at five colleges of medicine in the United States as part of a larger experimental, simulated instructional program. The performance of these students on these exams will be analyzed to test the hypothesis that these exams are parallel in terms of content based on the facet design analysis conducted. The Guttman-Lingo computer analysis as well as factor analysis will be used to test this hypothesis.

Discussion

Periodically, throughout the test development process, the steps defined by the facet design analysis were modified. These slight modifications did not sacrifice the rational approach to test development. Ideally, one should initially list all of the possible facet strings and eliminate the unrealistic ones. However, this is not a practical way of developing test blueprints since the number of dimensions is usually large. The test developers selected facet strings from the mapping sentence without actually listing all possibilities. Since the mapping sentence listed all of the relevant coordinates, the relevant facet strings were easy to visualize.

According to the rigorous interpretation of Guttman's theory, all of the items should be developed once the test blueprint defining the facet strings is specified (Martuza, 1977). Yet, realistically, this may not be the case. Teachers and test developers often rely on a pool of previously constructed and used items.

The test specification facet string used three facets; the item specification facet string used three facets, two of which were the same as in the test specification facet strings. An alternative approach would have been to develop two mapping sentences. The cardiologists believed that the elements in the disease category could be considered equivalent provided that the other coordinates of the facet string (e.g., A, B, and D) were the same. Pulmonary stenosis and coarctation were both low priority diseases. Therefore, an item which requires the student to describe the findings of an electrocardiogram from a patient with pulmonary stenosis (facet string $A_2B_3C_{20}D_3$) was considered equivalent to a question with the same requirements except from a patient with coarctation during the interpretation-of-laboratory-data-phase (Facet string $A_2B_3C_6D_3$). This hypothesis will be tested when the items are used with students.

Due to the criterion of the number of questions per disease, which was not included in the test specification facet strings, the assignment of items to an exam was not straightforward. If a larger pool of items had been developed, it would have been simpler to assign items. Instead, a smaller pool of items was originally developed and the cardiologists were asked to develop specific items once the test development began. However, the cardiologists agreed that developing items from item specification strings was a far simpler and less time consuming task than developing items from objectives without specific guidelines.

The original intent was to develop four parallel tests. Due to logistical problems, and level of difficulty of some items, only two exams were actually used. Although this increases the number of times each item is used, it does not violate the theoretical methodology, nor the notion that the tests are parallel. This revision of the original plan shows the strength and flexibility of facet analysis for item development in that plans can be changed throughout. It would also be possible later to construct additional tests using the same item specification as the original plan.

Recently, Governor Carey of New York signed a "truth-in-testing" bill which permits students to see their graded tests and the correct answers. Obviously, once students can see the actual exams, these items cannot be used again. Test specialists have been able to establish that alternate forms of an exam are parallel on the basis of consistent performance of different examinees. If items cannot be used repeatedly, then test specialists will need new ways to establish that alternative forms are indeed parallel. The method discussed in this paper is a potentially useful way of maximizing the probability of obtaining parallel forms which can be evaluated later. This facet design analysis might be especially useful for classroom exams.

The use of facet design appears to be a practical way to systematically develop equivalent forms of tests based on a logical analysis of the domain to be tested. This analysis ensures that tests are representative of the learning objectives. Since the actual development of a mapping sentence is not a time consuming activity, it is a viable strategy for content domain specification. If others agree that the mapping sentence logically represents the universe to be tested, then the a priori equivalence of the resulting tests can be established. The development of a large pool of items is a straightforward task when a facet string defines the content of each item. Thus, through the use of facet design, there is a logical justification to the claim that the alternative tests are equivalent in terms of content.

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Table 1

Test Specification Table Defined by Facet Strings

Facet String	Number of Questions
A1B1D1	1
A1B1D2	2
A1B1D3	1
A1B1D4	3*
A1B1D5	2
A1B1D6	4*
A1B2D1	1
A1B2D2	1
A1B2D4	2
A1B2D5	1
A1B2D6	3*
A1B3D1	2
A1B3D2	2
A1B3D4	2
A1B3D5	1*
A1B3D6	3
A2B1D1	2
A2B1D3	4*
A2B2D1	1
A2B2D3	4*
A2B3D1	1
A2B3D3	3*
A3B1D2	2
A3B1D3	1
A3B1D4	1
A3B2D1	1
A3B2D2	2
A3B2D4	1
A3B2D5	2
A3B2D6	1
A3B3D2	1
A3B3D3	1
A3B3D4	2
A3B3D5	2
A4B1D1	1
A4B1D3	1
A4B1D4	2
A4B2D1	1
A4B2D3	2
A4B2D4	1
A4B2D5	1
A4B3D3	1
A4B3D4	1
A5B1D1	1
A5B1D2	1
A5B1D5	2
A5B1D4	2
A5B2D4	2
A5B2D5	2
A5B3D2	1
A5B3D3	1
A5B3D4	2
A5B3D5	2
A5B3D6	2
A6B1D5	2
A6B1D6	1
A6B3D2	1
A6B3D4	1

The three facets are: A. type of multiple-choice question, B. prioritized objective and D. the step within the clinical process model. The number after each facet letter refers to the specific element of the facet as identified on Figure 2.

*More than two questions were desired for these facet strings because the cardiologists wanted to emphasize interpreting laboratory data, diagnosing diseases and pharmaceutical management regimens generally prescribed. By the nature of these questions they had to be low level types of questions. i.e., either recall information or verbally describe visual information.

Table 2

Exam A Item Specification Table Defined by Facet Strings

1. A4C1301
2. A2C701
3. A2C1501
4. A4C3404
5. A2C1103
6. A2C1303
7. A4C2004
8. A4C304
9. A2C303
10. A5C1504
11. A1C104
12. A1C204
13. A1C304
14. A5C2402
15. A1C706
16. A1C206
17. A1C1403
18. A5C1505
19. A6C1802
20. A1C2401
21. A6C506
22. A3C303
23. A6C604
24. A1C1306
25. A1C1005
26. A1C406
27. A6C1005
28. A1C504
29. A6C505
30. A1C506
31. A5C1604
32. A1C2405
33. A4C1805
34. A1C2401
35. A3C1002
36. A3C1002
37. A1C604
38. A1C404
39. A3C2405
40. A3C102
41. A4C1804
42. A4C404
43. A2C2203
44. A5C902
45. A2C103
46. A3C404
47. A5C1504
48. A5C1504
49. A5C1204
50. A3C1304
51. A3C1704
52. A3C405
53. A3C1202
54. A5C1205
55. A3C1801
56. A3C1206
57. A4C1801
58. A5C2303
59. A2C2003
60. A2C603
61. A2C1003
62. A2C1003
63. A2C403
64. A2C103
65. A5C2206
66. A1C1902
67. A5C1105
68. A5C2305
69. A1C705
70. A5C1104
71. A1C1002
72. A1C2402
73. A3C2402
74. A1C1004
75. A3C1605
76. A2C501
77. A4C603
78. A4C303
79. A4C1803
80. A5C1504
81. A1C1401
82. A1C1006
83. A5C2206
84. A5C605
85. A3C704
86. A1C2405
87. A4C1103
88. A2C1103
89. A2C403
90. A3C2405
91. A1C306
92. A1C706
93. A1C2202
94. A5C2301
95. A1C301
96. A1C2306
97. A3C1404
98. A1C2406
99. A3C1802
100. A3C2303

The three facets are: A. type of multiple choice question, C. name of disease and D. the step within the clinical process model. The number after each facet letter refers to the specicic element of the facet as identified on Figure 2.

TABLE 1

TEST SPECIFICATION TABLE DEFINED BY FACET STRINGS

FACET STRING	NUMBER OF QUESTIONS
A13101	1
A13102	2
A13103	1
A13104	3*
A18105	2
A18106	4*
A13201	1
A13202	1
A13204	2
A13205	1
A13206	3*
A13301	2
A13302	2
A13304	2
A13305	1*
A13306	3
A23101	2
A23103	4*
A23201	1
A23303	4*
A23301	1
A23303	3*
A38102	2
A38103	1
A38104	1
A38201	1
A38202	2
A38204	1
A38205	2
A38206	1
A38302	1
A38303	1
A38304	2
A38305	2

FACET STRING	NUMBER OF QUESTIONS
A48101	1
A48103	1
A48104	2
A48201	1
A48203	2
A48204	1
A48205	1
A48303	1
A48304	1
A58101	1
A58102	1
A58105	2
A58104	2
A58204	2
A58205	2*
A58302	1
A58303	1
A58304	2
A58305	2
A58306	2
A68105	2
A68106	1
A68302	1
A68304	1

The three facets are: A. type of multiple-choice question. B. prioritized objectives and C. the step within the clinical process model. The number after each facet letter refers to the specific element of the facet as identified on Figure 2.

More than two questions were desired for these facet strings because the cardiologists wanted to emphasize interpreting laboratory data, diagnosing diseases and pharmaceutical management regimens generally prescribed. By the nature of these questions they had to be low level types of questions. i.e., either recall information or verbally described visual information.

TABLE 2

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13. A1C304
14. A5C2402
15. A1C706
16. A1C206
17. A1C1403
18. A5C1505
19. A6C1802
20. A1C2401
21. A6C506
22. A3C303
23. A6C604
24. A1C1306
25. A1C1005
26. A1C406
27. A6C1005
28. A1C504
29. A6C505
30. A1C506
31. A5C1604
32. A1C2405
33. A4C1805
34. A1C2401
35. A3C1002
36. A3C1002
37. A1C604
38. A1C404
39. A3C2405
40. A3C102
41. A4C1804
42. A4C404
43. A2C2203
44. A5C902
45. A2C103
46. A3C404
47. A5C1504
48. A5C1504
49. A5C1204
50. A3C1304
51. A3C1704
52. A3C405
53. A3C1202
54. A5C1205
55. A3C1801
56. A3C1206
57. A4C1801
58. A5C2303
59. A2C2003
60. A2C603
61. A2C1003
62. A2C1003
63. A2C403
64. A2C103
65. A5C2206
66. A1C1902
67. A5C1105
68. A5C2305
69. A1C705
70. A5C1104
71. A1C1002
72. A1C2402
73. A3C2402
74. A1C1004
75. A3C1605
76. A2C501
77. A4C503
78. A4C303
79. A4C1803
80. A5C1504
81. A1C1401
82. A1C1006
83. A5C2206
84. A5C605
85. A3C704
86. A1C2405
87. A4C1103
88. A2C1103
89. A2C403
90. A3C2405
91. A1C306
92. A1C706
93. A1C2202
94. A5C2301
95. A1C301
96. A1C2306
97. A3C1404
98. A1C2406
99. A3C1802
100. A3C2303

The three facets are: A. type of multiple choice question, C. name of disease and D. the step within the clinical process model. The number after each facet letter refers to the specific element of the facet as identified on Figure 2.

FIGURE 1

A SAMPLE MAPPING SENTENCE (Millman, 1974)

A. REFERENT — B. REFERENTS COMMITMENT

The subject contributes to the
1. self
2. music education
3. general public
4. students

the
1. belief
2. feeling

C. LEVEL — D. ACTORS (e.e. music curriculum's) BEHAVIOR

that the
1. elementary
2. secondary

school music curriculm
1. should be
2. is

taught by

E. TEACHER
1. classroom
2. specialist

for the purpose of fulfilling

F. GENERAL STUDENT NEEDS
1. relaxation
2. means of expression
3. breaks from academics
4. emotional stimulation
5. self-discipline
6. fun time
7. contact with a human
8. group activity
9. uncover unknown talents
10. public performance
11. creative outlet
12. success
13. bring out shy students

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1. A through F are facets.
2. A1 through A4 are facet elements.
3. A1, B1, C1, D2, E2, F3 is a facet string.
4. An item based on the facet string in #3 above is:

   Do you believe that the elementary school music curriculum is taught by specialists for the purpase of giving students a break from academics?

Figure 2

In answering multiple choice items on a cardiology exam, students will

A. Employ cognitive Process

- A 1 recall factual information
- A 2 verbally describe visual information
- A 3 interpret factual information
- A 4 interpret visual information
- A 5 interpret information from various sources
- A 6 apply information from various sources.

when confronted with a

B. Disease priority category

- B 1 high priority
- B 2 medium priority
- B 3 low priorty

which presents as

C. Specific Disease

- C 1 acute MR
- C 2 AR
- C 3 AS
- C 4 ASD
- C 5 Angina - CAD
- C 6 Coarctation
- C 7 Congestive Cardiomyopathy
- C 8 Endocarditis
- C 9 Functional M
- C 10 Hypertension
- C 11 IIISS
- C 12 MVP
- C 13 MR
- C 14 MS
- C 15 Normal patient
- C 16 PDA
- C 17 Pericarditis
- C 18 Pul Hypertension-primary
- C 19 Pulm. Emboli
- C 20 Pulmonary Stenosis
- C 21 Rheumatic fever
- C 22 Vent Aneurysm
- C 23 VSD

at the stage when

D. The step involved within the clinical process

- D 1 data gathering
- D 2 order laboratory data
- D 3 interpret laboratory data
- D 4 diagnose patients problems
- D 5 determine management plan
- D 6 monitor on-going management

is required

Test specification involves Facets A, C, and D.
Item specification involves Facets A, B, and D.