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Applying automatic item generation to create cohesive physics testlets

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Abstract. Computer-based testing has created the demand for large numbers of items. This paper discusses the production of cohesive physics testlets using an automatic item generation concepts and procedures. The testlets were composed by restructuring physics problems to reveal deeper understanding of the underlying physical concepts by inserting a qualitative question and its scientific reasoning question. A template-based testlet generator was used to generate the testlet variants. Using this methodology, 1248 testlet variants were effectively generated from 25 testlet templates. Some issues related to the effective application of the generated physics testlets in practical assessments were discussed.

1. Introduction

The traditional item development using paper-and-pencil-based manual processes is inefficient. This is more pronounced when a large number of items are needed such as to fulfill the demands of items on the parallel test parcels or on the development of an item bank. The items are treated as isolated entities created, reviewed, and formatted individually. Since the items are developed individually, these items provide unpredictable statistical output because incidental and radical elements are not easily identified. The automatic item generation (AIG) [1,2] is a method for facilitating item development that accommodates the deficiencies of the traditional methods.

The AIG is a process of using models to generate test items with the help of computer technologies. Computer-based algorithms are used to place the material into the model through programming to generate the items automatically. All the values of the variables are systematically combined to generate items iteratively. Constraints are used to eliminate items that are unreasonable or meaningless.

The generations of items have been implemented in some software for various purposes. ModelCreator produces math narrative questions in several languages [3], ItemDistiller provides tools that can be used for sentence-based items [4], IGOR (Item Generator) software generates template-based items [5], Enhanced Automatic Question Creator (EAQC) extracts key concepts from text to generate multiple choice questions and constructive responses [6], and GenerEx automatically generates different versions of a basic competency test [7].

For objective items are concerned that present alternative answers with one correct answer, the majority of AIG implementations has been developed are for multiple-choice formats. The design and implementation of AIG for this dichotomous response are potentially modified in order to
accommodate the generation of testlet items for polytomies responses. The cognitive model includes the identification of the material to be tested, the development of cognitive processes to be revealed, and the development of the whole testlet structure. A TGEN [8] is a template-based program for generating testlets automatically.

The TGEN is an application program to generate testlet variants based on testlet models formatted in template forms. The program accepts and validates the input of a testlet template from the user, processes the testlet template into XML format, and generates testlet variants based on the testlet template. The TGEN accommodates multiple-choice and multiple-response items, images and numerical expressions both in stems and options, and fixed or conditional correct answers. The testlet templates in TGEN can be input manually by typing the templates directly into the system or they can be transferred in the form of word-processing documents. The TGEN general template in a word-processing document is shown on Figure 1.

| TESTLETID          | CONSTRAINTS                  |
|--------------------|------------------------------|
| Type a testlet ID here *) | Type constraint(s) here       |
| TOPICID            | ITEMNO                       |
| Type a topic ID of the testlet here *) | Type an item number here *)   |
| TESTLETSTEM        | ITEMSTEM                     |
| Type a stem of the testlet here *) | Type an item stem here *)    |
| TESTLETSTEMIMAGES  | ITEMSTEMIMAGES               |
| Type image file names inside the testlet stem here | Type image file names inside the item stem here |
| VARIABLES          | OPTIONS                      |
| Type declaration of variables here | Type options here *)        |
| CONDITIONALVARIABLES | KEY                        |
| Type declaration of conditional variables here | Type item key(s) here *)    |

**Figure 1.** A General TGEN template in a word-processing document.

A set of 25 cohesive physics testlet templates about mechanics had been developed. The templates were created based on 25 multiple-choice quantitative physics problems. The cohesive testlets were formed to stimulate deeper understanding of the contextual problems. The formation was done by revealing scientific processes explicitly namely by adding a qualitative question and its scientific reasoning question to all of the multiple-choice physics problems. The testlet templates were created by declaring manipulative variables and using them to manipulate the context of the problems. The variables were distributed throughout the testlet components such as in the testlet stems, the item stems, and the options. Changes in item development brought about by new forms of testlet-based testing have led to a question of to what extent the developed physics templates conformed to the TGEN features.

2. Methods
The design of this research was descriptive qualitative with the research targets were in the form of cohesive testlet templates for high school physics. The study aimed to provide an overview of the extent to which these physical testlet templates functioned meeting the perspective of generating items automatically using TGEN. This description was obtained through a functional testing or a black-box testing (BBT) that verifies proper handling of external functions provided by the program through its behavioural observation during execution [9,10].

The BBT used were a checklist of functional specifications that contain external functions that must exist and also the expected input and output information. These instruments facilitated the identification and verification of the compatibility characteristics of physics testlet templates with TGEN features in the perspective of AIG. The procedures involved inserting the physical testlet
templates into the TGEN system, validating the templates, and generating the testlet variants. The observation data of TGEN execution was used to verify checklist items and was analysed qualitatively to determine the fulfilment of the templates with the TGEN features.

3. Result and Discussion

The 25 testlet templates were developed based on 25 multiple-choice physics problems. The testlets were formed by adding a qualitative question and its scientific reasoning question to all multiple-choice physics problems. The testlet templates were created by declaring manipulative variables and used them to manipulate the context of the problems. The variables could be distributed throughout the testlet components such as in testlet stem, the item stem, and the options. A sample of testlet template from Elasticity and Hooke law, ELAST05, in normal format and in its word-processing document are shown on Figure 2 and Figure 3.

The manipulative variables and their values for the 32nd, 34th, 45th, 57th, and 64th testlet variants from the ELAST05 template are shown on Table 1. These selected five variants are depicted from all testlet variants resulted from a full combination of all of the manipulative variable values.

The values of all the manipulative variables on Table 1 were substituted as replacements for the manipulative variable codes on the testlet templates. The 64th testlet variant generated from the template ELAST05 is shown on Figure 4.

| Variant | Quantitative application | Qualitative analysis | Scientific reasoning |
|---------|--------------------------|----------------------|----------------------|
| 32nd    | I1=2; I2=5               | S1= the load is replaced with a pull force F equals to W; S2=spring constant; S3=elasti05b.png | S7=The underlying principle; S1= the load is replaced with a pull force F equals to W |
| 34th    | I1=2; I2=4               | S1= the load is replaced with a pull force F equals to W; S2=spring restoring force; S3=elasti05b.png | S7=Arguments that explain; S1= the load is replaced with a pull force F equals to W |
| 45th    | I1=2; I2=6               | S1=a force F exerted on the load; S2=spring constant; S3=elasti05c.png | S7=Arguments that explain; S1=a force F exerted on the load |
| 57th    | I1=3; I2=6               | S1=the load is removed; S2=spring constant; S3=elasti05a.png | S7=Supportive basic statements; S1=the load is removed |
| 64th    | I1=3; I2=4               | S1=the load is removed; S2=spring restoring force; S3=elasti05a.png | S7=Supportive basic statements; S1=the load is removed |
### TEMPLATE ID: ELAST05

**Topic:** Elasticity and Hooke law

| Manipulative variables: | Conditional manipulative variables: |
|-------------------------|-------------------------------------|
| I1: \{2,3\}            | If S1='load removed', so S3='elasti05a.png' |
| I2: \{4,5,6\}          | If S1='the load is replaced with a pull force F equals to W', so S3='elasti05b.png' |
| S1: {'load removed’, ‘the load is replaced with a pull force F equals to W’, ‘a pull force F exerted on the load'} | If S1='a tensile force F exerted on the load’, so S3='elasti05c.png' |
| S2: {'spring constant’, ‘spring restoring force’} | If S2='spring constant’, so S4='change of spring length', S5='ratio of restoring force and change of spring length', S6='resultant of external forces' |
| S7: {'Supportive basic statements’, ‘The underlying principle’, ‘Arguments that explain'} | If S2='spring restoring force’, so S4='resultant of external forces', S5='restoring force not', S6='change of spring length' |

#### Item ID: ELAST05-01

A spring is loaded with I1 kg mass as shown in the right picture. If the length of the spring increases I2 cm, and the earth gravitation is 10 ms^-2, the elastic potential energy of the spring is …

- A. \([0.5*I1*10*I2/1000]\) joule
- B. \([0.5*I1*10*I2/100]\) joule
- C. \([I1*10*I2/100]\) joule
- D. \([0.5*I1*10*I2/100*12]\) joule
- E. \([0.5*I1*10*I2]\) joule

Key: fixed – B

#### Item ID: ELAST05-02

If S1 and the condition is shown by the picture, so the value of S2 now is:

- A. zero
- B. fixed and greater than zero
- C. become bigger
- D. become smaller

Key: conditional
- If S1= ‘load removed’ and S2=’spring constant’, key=B
- If S1= ‘load removed’ and S2=’spring restoring force’, key=A
- If S1= ‘load is replaced with a pull force F equals to W’ and S2=’spring constant’, key=B
- If S1= ‘load is replaced with a pull force F equals to W’ and S2=’spring restoring force’, key=B
- If S1= ‘a pull force F exerted on the load’ and S2=’spring constant’, key=B
- If S1= ‘a pull force F exerted on the load’ and S2=’spring restoring force’, key=C

#### Item ID: ELAST05-03

S7 the situation of spring problem if S1 is:

- A. The value of S2 depends on the value of S4.
- B. The spring has S2 which always has a fixed value.
- C. The value of S5 depends on the value of S6.

Key: conditional
- If S2=’spring constant’, key=B
- If S2=’spring restoring force’, key=A

**Figure 2.** Testlet template for Elasticity and Hooke law ELAST05.
| TESTLETID | ELAST05 |
|-----------|---------|
| TOPICID   |         |
| ELASIT    |         |
| VARIABLES |
| N1 [2 | 3] |
| N2 {5 | 6} |
| S1 {load removed | load is replaced with a force F equals to W | a force F exerted on the load} |
| S2 {spring constant | spring restoring force} |
| S7 {Supportive basic statements | The underlying principle | Arguments that explain} |
| CONDITIONAL VARIABLES |
| S1 {load removed} || S3 {elast05a.png} |
| S1 {the load is replaced with a pull force F equal to W} || S3 {elast05b.png} |
| S1 {a tensile force F exerted on the load} || S3 {elast05c.png} |
| S2 {spring constant} || S4 {change of spring length} :: S5 {ratio of restoring force and change of spring length} :: S6 {resultant of external forces} |
| S2 {restoring force} || S4 {resultant external forces} :: S5 {restoring force not} :: S6 {change length} |
| ITEMNO | 1 |
| ITEMSTEM |
A spring is loaded with 11 kg mass as shown in the right picture. If the length of the spring increases 2 cm, and the gravitational is 10 m/s², the elastic potential energy of the spring is ... |
| ITEMSTEMIMAGES |
elasti05.png |
| OPTIONS |
| 0.5*N1*10*N2/1000 Joule |
| 0.5*N1*10*N2/100 Joule |
| N1*10*N2/100 Joule |
| 0.5*N1*10*N2/100*N2 Joule |
| 0.5*N1*10*N2 Joule |
| KEY |
| B |
| ITEMNO | 2 |
| ITEMSTEM |
If S1 and the condition is shown by the picture, so the value of S2 now is: |
| ITEMSTEMIMAGES |
S3 |
| OPTIONS |
| zero |
| fixed and greater than zero |
| become bigger |
| become smaller |
| KEY |
| S1 {load removed} :: S2 {spring constant} || B |
| S1 {load removed} :: S2 {spring restoring force} || A |
| S1 {the load is replaced with a pull force F equal to W} :: S2 {spring constant} || B |
| S1 {the load is replaced with a pull force F equal to W} :: S2 {spring restoring force} || B |
| S1 {a pull force F exerted on the load} :: S2 {spring constant} || B |
| S1 {a pull force F exerted on the load} :: S2 {spring restoring force} || C |
| NOTITEM |
| 3 |
| ITEMSTEM |
S7 the situation of spring problem if S1 is: |
| OPTIONS |
The value of S2 depends on the value of S4. |
The spring has S2 which always has a fixed value. |
The value of S5 depends on the value of S6. |
| KEY |
| S2 {spring constant} || B |
| S2 {spring restoring force} || A |

**Figure 3.** Testlet template ELAST05 in word-processing document.
Problem 11

A spring is loaded with 3 kg mass as shown on the right picture. If the length of the spring increases 4 cm, and the gravitation is 10 m s⁻², the elastic potential energy of the spring is …

A. 0.06 joule  
B. 0.6 joule  
C. 1.2 joule  
D. 2.4 joule  
E. 60 joule

a) If the load is removed so the condition is as on the picture shown, the value of the restoring force now is:

A. zero  
B. fixed and greater than zero  
C. become bigger  
D. become smaller

b) Supportive basic statements to spring problem situation if the load is removed is:

A. The value of the spring restoring force depends on the value of external force resultant.  
B. The spring has an elastic restoring force that always has a fixed value.  
C. The value of restoring force does not depend on the change of spring length.

Figure 4. The 64th testlet variant generated from the ELAST05 template.

The 25 templates were all about mechanics including five subtopics each of which was with five developed templates. The number of manipulative variables employed in each template and the corresponding testlet variants generated are summarized on Table 2.

Table 2. Number of manipulative variables and variants.

| Subtopic                             | Template | T1  | T2  | T3  | T4  | T5  |
|--------------------------------------|----------|-----|-----|-----|-----|-----|
| Kinematics and dynamics              |          | 3/72| 4/72| 4/60| 5/90| 9/120|
| Elasticity and Hooke law             |          | 10/432| 4/90| 4/32| 5/216| 9/108|
| Work and energy                      |          | 6/360| 9/216| 4/90| 4/120| 4/120|
| Energy conservation law              |          | 5/54| 9/384| 3/75| 12/72| 11/216|
| Impulse, momentum and collision      |          | 9/312| 6/180| 6/216| 6/384| 6/168|

1248 testlet variants were generated effectively from 25 physics testlet templates. The generation process was done using an AIG method facilitated by a template-based testlet generator, TGEN. The generated testlet variants had a pedagogic feature of stimulating qualitative analysis in physics problem solving. The testlet variant specific objectivity could be employed in developmental examinations for fostering deeper understanding of physics by mixing the formula-based and the concept-based assessments.

The BBT testing through a controlled experiment during program execution of the 25 physical testlet templates was performed to ensure that the physical testlet templates were in line with the TGEN testlet generator functionality. This test revealed a "demonstration of proper behavior" [9] from the generation of testlet variants based on the physics testlet templates. The results could be interpreted as giving the evidences about the quality of the cohesive physics testlet templates in the context of AIG.
4. Conclusion
The 25-cohesive physics testlet templates were conformed in the perspective of AIG to the TGEN features. 1248 testlet variants were generated effectively from the templates. The generation process was done using AIG method facilitated by a template-based testlet generator, TGEN. The generated testlet variants have a pedagogic feature of stimulating qualitative analysis in physics problem solving. The testlet’s specific perspective could be applied to some practical assessments for revealing in-depth understanding of physics.

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