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Ontological Descriptions of Statistical Models for Sharing Knowledge of Academic Emotions

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Abstract: Many studies have been conducted during the last two decades examining learner reactions within e-learning environments. In an effort to assist learners in their scholastic activities, these studies have attempted to understand learner mental states by analyzing participants' facial images, eye movements, and other physiological indices and data. To add to this growing body of research, we have been developing IMS (Intelligent Mentoring System) which performs automatic mentoring by using an ITS (Intelligent Tutoring System) to scaffold learning activities and an ontology to provide a specification of learner's models. To identify learner mental states, the ontology operates based on theoretical and data-driven knowledge of emotions. In this study, we use statistical models to examine constructs of emotions evaluated in previous psychological studies, and then produce a construct of academic boredom.

Keywords: Ontology, academic emotions, academic boredom, constructs

1. Introduction

During the last two decades, studies have been conducted that examine semiconscious behaviors of learners participating in e-learning environments by observing and analyzing facial images, eye movements, and other physiological indices. Analysis of data obtained from such examinations enables researchers to understand various mental states of learners, such as that of "confidence" and "confusion" (Arroyo et al., 2009; Muldner et al., 2009). In addition, studies have employed the intelligent tutoring system to evaluate the structural features of the knowledge learners possess. As a result of these studies, researchers have developed an intelligent mentoring system (IMS) that supports learning based on the various aspects of mental states and knowledge (Kojima et al., 2012; Muramatsu et al., 2012; Muramatsu et al., 2013). One of its main characteristics is diagnostic function of learner model considering mental states of learners. Because mental states can instantly change in a short activity (e.g., solving of a single problem), IMS is required to monitor learners at all time and give feedback based on diagnosis. The IMS provides integrative learning-support including real-time estimation of learners' mental states and selection of ways to support learners, in addition to diagnosis of learners' knowledge structures and determination of teaching strategies provided by ITS (Intelligent Tutoring System). In the IMS, data from interactions between users and the system are captured according to two levels of cognitive activity: high-level interactions (HLI) and low-level interactions (LLI). HLI examine a user's explicit awareness of scholastic activities and illustrates it by means of a data resource that employs large grain samples. By contrast, LLI examine user's diffuse awareness to a limited extent and illustrates it by means of a data resource that uses much smaller grain samples.

Muramatsu et al. (2012) developed an ontology that provides descriptions of the relationships among LLI resources and the mental states of learners. These descriptions are based on specific tasks performed by learners, which are independent of the knowledge structures examined within specific domains which they learn about. Muramatsu et al. (2013) expanded the ontological descriptions pertaining to mental states based on concepts of academic emotions (Pekrun et al. 2002) and the control-value theory (Pekrun 2006). These descriptions help to clarify relationships between academic emotions and subjective attributes that perform the role of subjective control or value in accordance with the control-value theory. Their ontology effectively illustrates how academic emotions are formed during co-occurrence of control and value, and it has helped researchers interpret learners' mental states based on LLI resources in the IMS. However, the descriptions provide insufficient detail to identify subcategories of attributes that perform a role of control or value in practical settings. The subcategories derive from experiments that measure emotions using rating scales and statistical analyses of the measured data. To implement the IMS, ontological descriptions about academic emotions should include both data-driven and theoretical knowledge. The academic emotions are student's emotions experienced in academic settings such as class-related, learning-related and test-related situations (e.g. boredom experienced in classroom instruction, enjoyment of learning and test anxiety).

This study makes a conceptualization of statistical models such as the factor analysis model used in psychological research. Specifically, we describe the structure of rating scales that express psychological attributes as representations, and specify relationships among variables that represent the psychological attributes in statistical models. Finally, we demonstrate ontological descriptions in constructs of academic emotions.

2. Emotions in Academic Settings

In the field of psychology, learner emotions, specifically within the context of classroom instruction and achievement, are referred to as academic emotions (Pekrun et al., 2002). Emotions related to achievement are defined as achievement emotions and are measured by using the achievement emotions questionnaire (Pekrun et al., 2011). This questionnaire consists of scales related to nine emotions: enjoyment, boredom, anger, hope, anxiety, hopelessness, pride, relief, and shame. These nine emotions can be subdivided into two types according to their object focus: (1) activity emotions, which pertain to ongoing achievement-related activities, and (2) outcome emotions, which concern the outcomes of these activities. Enjoyment, boredom, and anger constitute activity emotions. The outcome emotions include *prospective* outcome emotions such as hope, anxiety, and hopelessness, as well as *retrospective* outcome emotions such as pride, relief, and shame.

Academic emotions are explained by referring to the control-value theory proposed by Pekrun (2006). This theory describes emotions as sets of interrelated psychological processes composed primarily of affective, cognitive, motivational, and physiological dimensions (Pekrun et al., 2011). The theory appraises the subjective control and subjective value. The appraisal of subjective control relates to perceived control of achievement-related actions and outcomes. By contrast, the appraisal of subjective value pertains to the subjective importance of achievement-related activities and outcomes.

In e-learning environments, learning materials such as multiple-choice tests are considered as "object focuses," and activity emotions such as enjoyment, boredom, and anger can arise in such settings. For example, when a learner's mental states are estimated as "interesting" and "comprehending," enjoyment is expected to be the academic emotion experienced. In this situation, the quality of "interesting" has a subjective value, which includes a quality value of positive or negative, because subjective evaluation on the quality of "interesting" correlates to a positive/negative affection (Acee et al., 2010). However, when an activity involves a learning material that lacks incentive value, whether positive or negative, boredom is the expected result. The incentive value of an activity may depend on the control that is perceived by the learner (Pekrun, 2006).

According to research on the construct of academic boredom, a learner's perceptions of boredom also represent a situation-dependent construct (Acee et al., 2010). Specifically, over-challenging situations lead learners to either "task-focused" or "self-focused" boredom, while under-challenging situations lead to more general boredom. In the research of Acee et al., the academic boredom scale (ABS) was used to measure learners' emotions. The ten items in ABS (ABS-10) consist of unipolar scales that correspond to ten psychological attributes, which are listed as follows: "want something else," "tired of activity," "impatient," "frustrated/annoyed," "apathetic," "nothing to do," "activity dull," "repetitive," "wonder why doing this," and "useless/unimportant." As a result of a factor analysis of data related to under-challenging situations, all items in the ABS-10 scale were correlated to general boredom. By contrast, a factor analysis of data related to over-challenging situations correlated five psychological attributes ("want something else," "tired of activity," "impatient," "frustrated/annoyed," and "apathetic") to self-focused boredom. The other five attributes ("nothing to do," "activity dull," "repetitive," "wonder why doing this," and "useless/unimportant") were correlated to task-focused boredom. Because the variables derived from these factor analyses yield psychosocial attributes measured through the use of rating scales, the relationships among them provide a construct of academic emotions and their subcategories.

3. Method for Ontology Development

3.1 Role Concept

Ontological engineering is a field of computer science that supports the systematic description of knowledge. From this knowledge-based perspective, "ontology is defined as a theory (system) of concepts/vocabulary used as building blocks of an information processing system (Mizoguchi et al., 1995)." In Hozo[1] ontology editor which is one of ontology development environment, each node represents a whole concept and contains slots that represent part-of or attribute-of relations (Fig. 1).

Hozo helps describe role concepts wherein a role depends on the contents of each whole concept. For example, a teacher's role is played only in the context of school. Every slot thus has a role within a whole concept that implies a context. In the context, a class of instances that can play a role is defined by a class constraint and is called a role holder (Kozaki et al., 2000). In this way, the role concept distinguishes between concepts within different contexts. Inherited role holders and class constraints imported from other ontologies are shown in the right half of Figure 1.

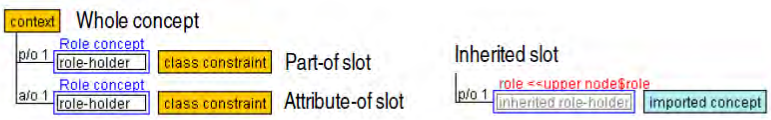

Figure 1. Legend.

3.2 Top-level Ontology

Mizoguchi (2010) constructed a top-level ontology based on the role concept theory known as "yet another more advanced top-level ontology" (YAMATO[2]). Based on YAMATO, an entity is divided into three classes: physical, abstract, and semi-abstract. Although instances of a physical class require 3D space and time to exist, instances of an abstract class require neither. Instances of a semi-abstract class require only time to exist, and the class contains mind, representation, content, and a representation form.

Representations such as novels, poems, paintings, music, and symbols are distinguished from their propositions and forms of representation (Mizoguchi, 2004). A class of representation is further divided into primitive representation and composite representation. The composite representation has one or more part-of slots which indicates that a subsidiary role is played by a representation. The representation contains part-of slots that indicate a content role played by a proposition and a form role played by a representation form. The proposition is divided into two classes: representation-primary and representation-secondary. For example, "content of a piece of music" and "content of a novel" are examples of the former and "content of a fact recognized by a human" is an example of latter. These classes necessarily depend on their representation. However, instances of a representation-secondary class, such as facts, data, and thoughts, indicate original content that should be represented. For example, a fact designated as an event exists before it can be recognized and expressed as a representation. In this sense, the process of human recognition, which necessarily includes sensations and perceptions, belong to the representation-secondary class.

The main features of YAMATO are definitions of qualities and quantities, their representations, and descriptions of their interrelationships in other top-level ontologies. Attributes of entities are represented as qualities comprised of quality values. A quality value is divided into a class of "categorical" and a quantity contains a quantitative quantity and a qualitative quantity. A quality is divided into a property and generic quality, with the property being an abstraction of the generic quality

[1] http://www.hozo.jp

[2] http://www.ei.sanken.osaka-u.ac.jp/hozo/onto_library/upperOnto.htm

but possessing a quality value. The generic quality is divided into intrinsic generic quality and accidental generic quality. A subclass of intrinsic generic quality is basic generic quality, which contains quantitative generic quality and qualitative generic quality.

In YAMATO, a representation of a quality is distinguished from a real quality which exists with an entity. Therefore, representations of qualities and quantities are defined as transformations of real quality through an “action to measure.” The measure contains a part-of slot that indicates a “result” role played by a primitive representation. A quality measurement is defined as a role-holder performed by a proposition in a content role subslot of the result role slot. Through measurements, data are approximation of real qualities and a quality value representing a true value is independent of any measurements. Therefore, representations of a quality must be distinct from representations of a quality obtained through measurements (Masuya et al., 2011).

4. Ontological Descriptions

4.1 Subjective Measurement

In psychometric methods that use rating scales, subjective evaluations of emotions are often expressed as points on a scale. The *rating scale* and *point on rating scale* are displayed in Figure 2. A point on the rating scale has a form slot that is filled by a *word* or *pictogram* and contains an additional slot in which a number represents a scale marking. The rating scale is a composite representation comprised of multiple points. Two points are considered *anchor* role-holders in which a *pole* subslot indicates a perceptual large or small point.

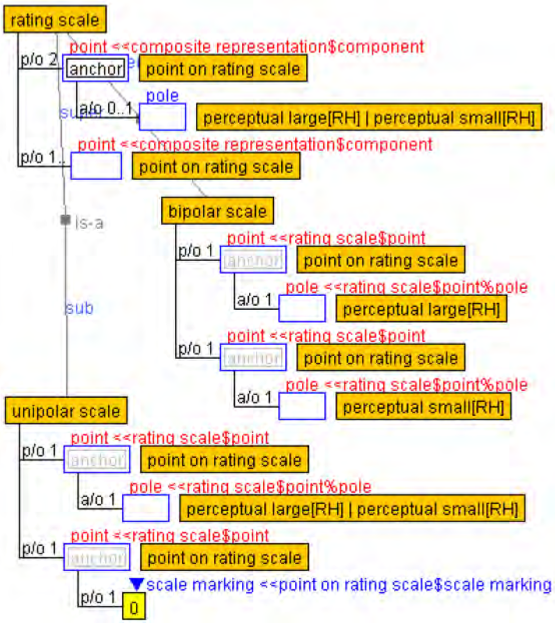

Figure 2. Rating Scale and its Points.

Semantic differential scales contain adjective pairs that represent perceptual qualities, each of which indicates large or small perceptual quality values. Thus, the relationship of magnitude among perceptual quality values can be defined through the rating scale. Furthermore, *unipolar* and *bipolar scales*, defined as subclasses of the rating scale, contain unipolar and bipolar perceptual qualities, respectively.

4.2 Statistical Models

To show relationships between measured data of emotions in subjective ways, statistical models are often adopted in psychological research. In this study, we employed unique mathematical models as well as mathematical and quality data expressions (Fig. 3) in the composite representation in

YAMATO. The *mathematical model* contains a *mathematical expression* slot inherited from the *composite* and *quality data* slot. Each role of the slots employs a mathematical expression and *quality data representation*. In the mathematical model, the content of the quality data is defined as a *modeled attribute value*, while the mathematical expression is composed of multiple *variables* inherited from the *component* slot and *constant* slot. The variable role contains a representation and coefficient performed by a number defined as a subslot.

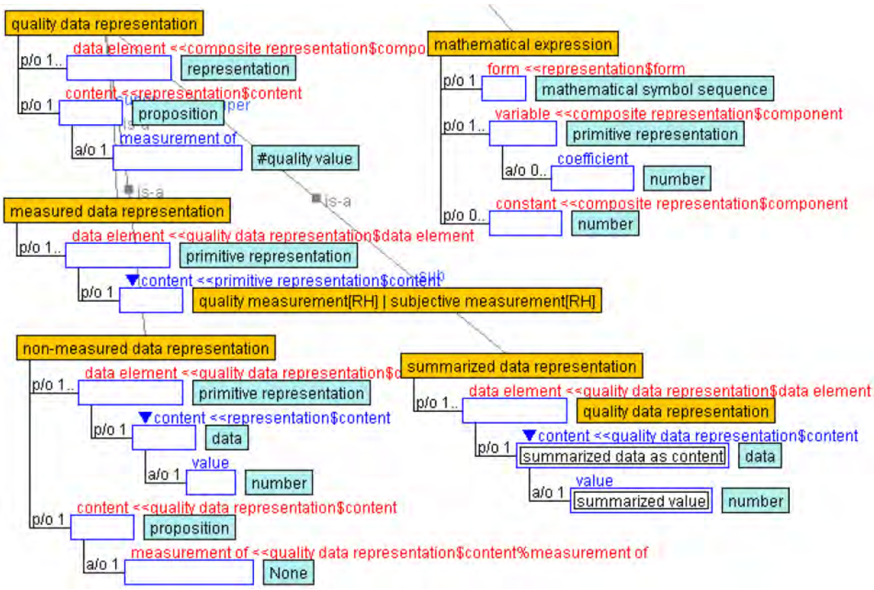

Figure 3. Mathematical Model and its Components.

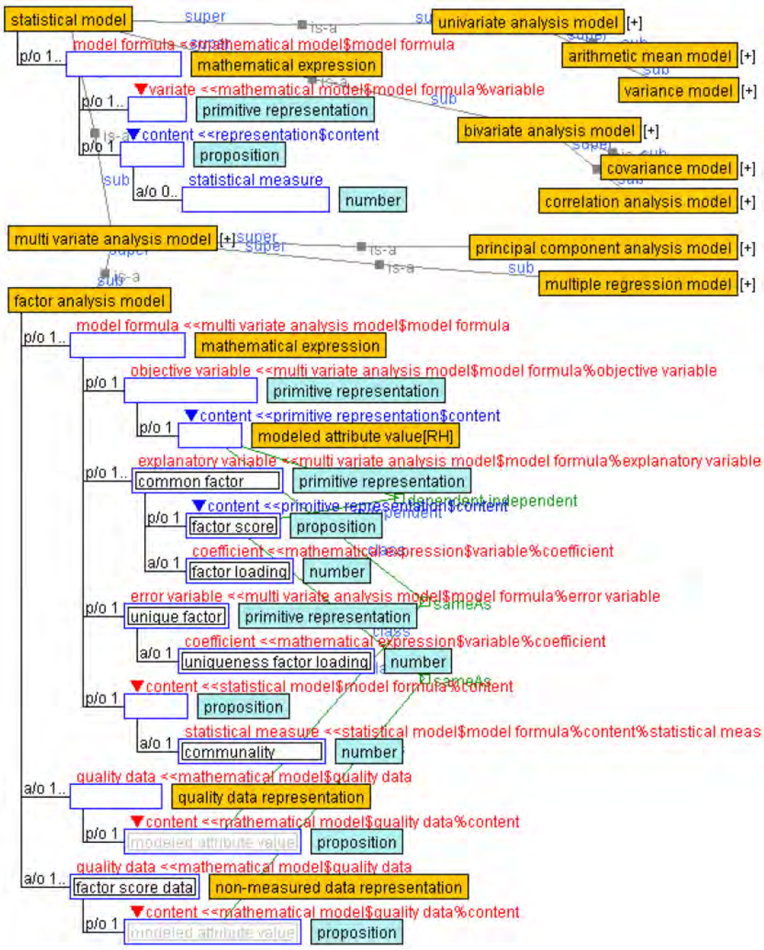

Figure 4. Classes of Statistical Models.

The quality data representation contains multiple *data element* role slots performed by other representations. The content role slot is performed by the data and the *measurement of* the subslot indicates the derivation. The quality data representation is divided into *measured data representation*, *non-measured data representation*, and *summarized data representation*. In the measured data representation, the content is performed by the quality measurement or subjective measurement, which indicates quality value as a proposition. However, the content of the non-measured data representation such as factor scores and principle component scores exists only in mathematical models. The summarized data representation is composed of data elements played recursively by the quality data representation, and its content is regarded as *summarized data as content*, which represents a summarized value such as an average.

Figure 4 displays the hierarchy of statistical models and their subclasses. The statistical model is divided into a *univariate analysis model*, *bivariate analysis model*, and *multivariate analysis model* by cardinality of the quality data representation slot. The univariate and bivariate analysis models employ summary statistics such as arithmetic mean, variance, covariance, and correlation. Multivariate analyses such as multiple regression, factor analysis, and principle component analysis are defined as subclasses of the multivariate analysis model. Objective and explanatory variables are described in a *model formula* slot and have a "dependent-independent" link to indicate their correspondences. The data to be assigned to the variables is described by a "same as" link between the content slots of variables and the data representations.

5. Discussion and Conclusion

In this section, we discuss the validity and utility of the ontological descriptions discussed in the previous section through a demonstration of the construct of academic boredom. The results of a factor analysis conducted by Acee et al. (2010) indicate that academic boredom is comprised of multidimensional and situation-dependent constructs. First, some items on the ABS-36 are correlated to negative and positive values. Second, all items on the ABS-10 are correlated to general boredom in under-challenging situations. The ABS-10 consists of ten items representing ten psychological attributes: "want something else," "tired of activity," "impatient," "frustrated/annoyed," "apathetic," "nothing to do," "activity dull," "repetitive," "wonder why doing this," and "useless/unimportant." Third, in over-challenging situations, five psychological attributes ("want something else," "tired of activity," "impatient," "frustrated/annoyed," and "apathetic") are correlated to self-focused boredom, whereas the remaining five attributes ("nothing to do," "activity dull," "repetitive," "wonder why doing this," "useless/unimportant") are correlated to task-focused boredom.

This construct of academic boredom is represented in Figure 5 and, as a subclass of the factor analysis model, is further defined in Figure 4. Model formulae given in mathematical expressions (Fig. 3) are defined as *Negative Affect-related Expression* and *Positive Affect-related Expression* role holders, which indicate relations between object variables and factors. The object variables contain a content slot used by a *modeled attribute value*, which is defined as a proposition of a quality data representation (Fig. 3). This means that the modeled attribute value refers to a quality value measured with a rating scale (Fig. 2). Therefore, correlations between some items of the academic boredom scale and negative/positive values are adequately described.

The constructs of boredom in under- and over-challenging situations are represented in Figure 5. In the *Construct of Academic Boredom in Under-challenging situation*, the modeled attribute value that is correlated to the *General Boredom Factor* refers to a quality value measured with a rating scale. Types of qualities are specified by the role player in the *measurement of* role slot. For example, a quality measured by the ABS-10 such as "want something else," "tired of activity," or "impatient" can play the role. Similarly, modeled attribute values in the *Construct of Academic Boredom in Over-challenging situation* also refer to qualities measured by the ABS-10.

This study conceptualized the three features of the boredom construct derived from the factor analysis conducted by Acee et al. (2010). However, two issues remain. First, qualities measured by items in the ABS lack sophistication. Second, the construct of academic boredom is uncertainly positioned in the description of statistical models. In this study, we provided an adequate description of relationships between modeled attribute values and quality values measured with rating scales.

However, we did not address modeled values described by the rating scales, a topic that we hope to examine in the future. Furthermore, we offered tentative descriptions of the constructs of academic boredom and positioned them in the statistical models. The concepts related to these constructs fundamentally differ from general statistical models. In other words, the constructs should be conceived in ways similar to learner models, for example. We addressed these unresolved matters in this study.

Our ontology will enable researchers to better interpret their results and share their findings. The descriptions we provide of constructs of academic boredom can help researchers acquire knowledge about associations between academic emotions and psychological attributes. Because the descriptions provided in the current study derives from only single study, their capability and range of application are confined to a construct of the academic boredom from a viewpoint of a few researchers. However, basic forms of statistical models which represent the constructs of academic emotions are common in psychology. Thus the current study just proposed the descriptions as a framework of the knowledge sharing on academic emotions. In future work, we extend our descriptions of constructs to include various academic emotions studied in educational psychology, and conduct practical assessments of their validity and utility through an implementation of IMS.

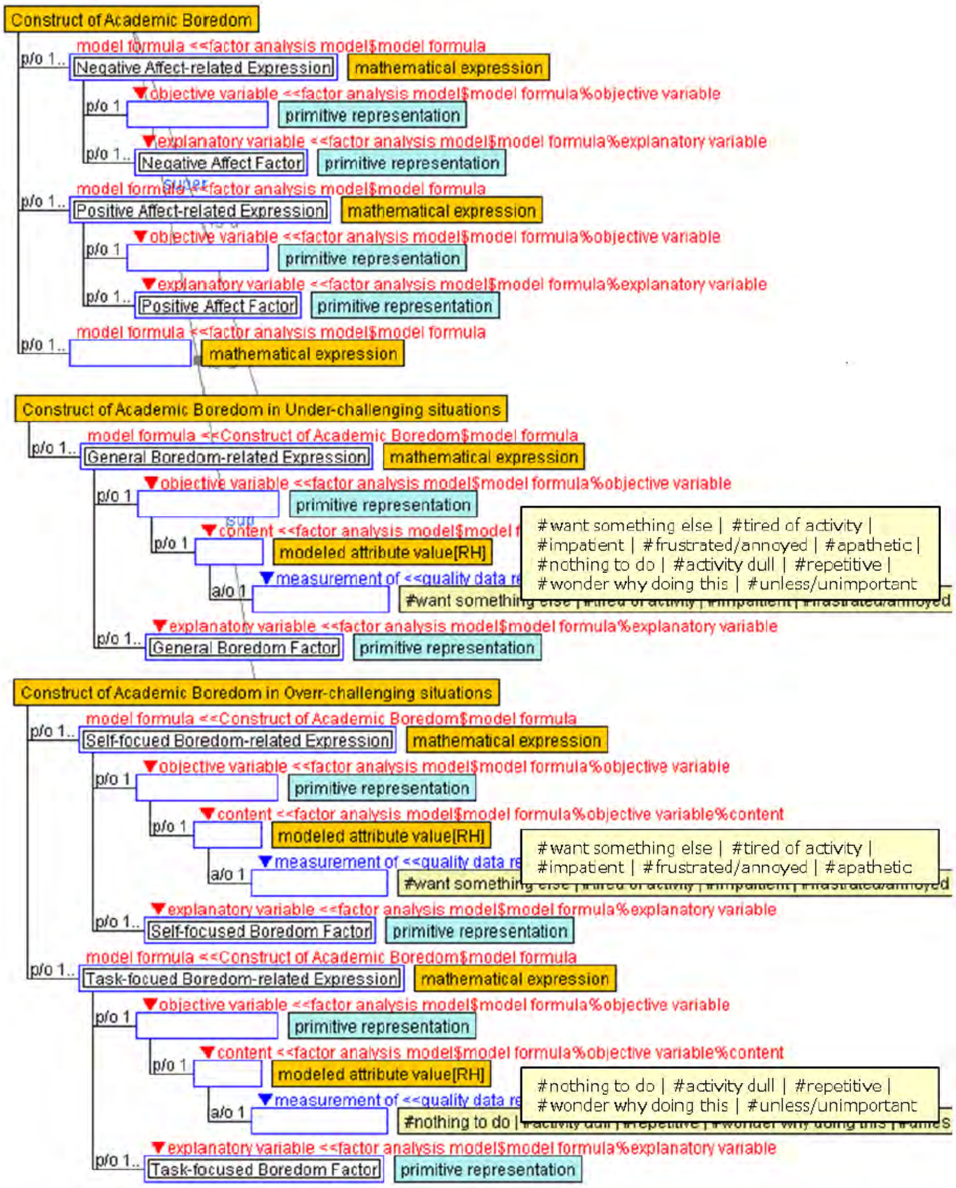

Figure 5. Construct of Academic Boredom.

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