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Model of Domain Learning Based Skill Assessment: Instrument Set Flexibility

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Model of Domain Learning Based Skill Assessment: Instrument Set Choice Flexibility & Complexity

The assessment of students' development in their professional skills has been discussed to be challenging not only for the engineering curriculum but also in other undergraduate programs, including information sciences, business, and other disciplines. Given the importance of developing these skills in students, an assessment framework based on the Model of Domain Learning (MDL) is proposed. The use of MDL is aimed at providing flexibility and practicality in the assessment of these skills. In this paper, the implementation of an assessment framework for the creative problem solving skills is presented. Included empirical study results not only point to the advantages of having a flexible assessment framework, but also highlight its advantages in covering interest and strategic processing development along with knowledge to monitor learning in creative problem solving. Complexity of choosing appropriate instruments for the assessment framework is also discussed.

Introduction

In this paper, developing an assessment framework to measure student's creative problem solving abilities throughout their education is discussed. The assessment framework is designed to be modular in such a way that (1) assessment instruments can be tailored for the class standing of students within their curriculum, (2) both course and overall curriculum level assessments are possible, where the assessment scores reflect the development on an absolute scale, and (3) instruments and rubrics can be upgraded over time to reflect the progress in the assessment of specific professional skills.

The Model of Domain Learning (MDL) proposed by Alexander et al.[1] is a learning theory characterized by the interrelations that exist between the learning-based constructs and the experience-based stages in academic domains. In this study, the MDL based framework is applied to develop assessment rubrics mapped to the interaction between the experience-based stages and the learning-based components. The experience-based growth stages in ascending order of experience include acclimation, competency, and proficiency. The learning-based components include interest, knowledge, and strategic processing. Interactions among the learning-based components and experience-based stages are used to explain students' progression in specific professional skills throughout their educational journey[15]. The interest, knowledge and strategic processing abilities of the students are expected to evolve over time to achieve the proficiency level to some extent. Students have mainly situational interest at the acclimation stage because a new topic is introduced. In the competency stage, students show an increased interest due to a commitment to a specific field of study. Finally, in the proficiency stage, interest becomes an individual interest, which means there is a long term personal connection resulting in further exploration in the specific field of study. Similarly, students have limited knowledge about the specific field of study in the acclimation stage whereas in the proficiency stage, the knowledge becomes broad and deep. For the last component of the MDL, i.e., strategic processing, students are not able to link the knowledge gained during acclimation stage. Next in the competency stage, although students are still using surface level strategies, they are gradually beginning to use deep processing strategies. Finally, in the proficiency stage, deep processing strategies have been fully utilized to solve problems.

The MDL has been studied in the domains of social studies, astrophysics, human biology/immunology, educational psychology, and special education, by involving students from elementary through graduate school[1,2,3,4]. Additionally, the MDL is tested in such domains as technology, music therapy, and physical education[5,6,7]. However, there are not studies on the use of MDL in the science, technology, engineering or mathematics (STEM) domains to assess students' professional skill development. This work is among the first studies that use the MDL theory in the assessment of professional skills in STEM, particularly in creative problem solving, teamwork, global awareness and ethics.

In the literature, various instruments and rubrics are suggested for the assessment of professional skills. These assessment tools use different models; and identified learning outcomes are scored based on different scales. Assessment approaches also vary across the professional skill domains. For example, peer assessment is frequently used in the teamwork domain[8,9,10,11,12], but case studies are preferred in the domain of ethics[13,14]. Therefore, integrating various assessment tools into an overall program of assessment and interpreting assessment results from multiple sources are challenging. The proposed MDL-based framework aims to analyze and evaluate student progress in different professional skills based on the same theoretical framework. If assessment tools are designed based on this uniform framework, assessment data from multiple tools over different domains can be gauged using the same scale. Thereby, student progress in different professional skills can be compared. Such an analysis can provide a better picture of what is lacking and how to improve the programs and strategies attempting to improve students' professional skills in the chosen areas. As part of our previous work in the domain of teamwork communication[15], we observed that third and fourth year students performed better in a teamwork communication test, which was designed based on the proposed framework, than first and second year students. However, this performance improvement was mainly due to students' increased ability to solve problems, rather than their increased knowledge in the teamwork communication domain. Furthermore, students' interest in teamwork communications did not increase, which indicated a gap in their professional development.

We have designed the MDL-based assessment framework in such a way that assessment instruments can be tailored for the specific class standing of students within their curriculum. This is a direct result of mapping the learning outcomes and the assessment items against the MDL framework. The Peer Evaluation & Assessment Resource (PEAR) system[9], which is a web-based application designed to implement the proposed assessment framework, allows instructors to choose assessment items to create customized rubrics for their courses; and provides feedback about where the chosen items fall within the framework. Using this feedback, instructors can appropriately tailor the assessment to the class level or learning objectives.

In our previous work, empirical evidence has been provided for the achieved flexibility and practicality of the MDL assessment framework, and its implementation on a specific case of teamwork communication was shown. In this paper, the focus is on the flexibility for instrument selection and upgradability, and we cover creative problem solving as a case. The paper will present the modular MDL framework as well as the repertoire of instruments recommended and used for creative problem solving skills. In the sections below, background information is provided on creative problem solving, the professional skill used in this study; the instrument selection process adopted to choose the current set of instruments is discussed; and finally, completed data collection along with its results is presented.

Creative Problem Solving

How do we define, or assess a person's creative potential? Can it be enhanced, i.e., can a person learn to be more creative? These questions relate to a deep discussion of creativity as a process to be taught along with pertinent tools, as well as an inherent disposition for openness to and sustained interest to be creative. Yet another dimension of creativity might be of creative performance captured in a short (e.g., laboratory task) or a long period of time (e.g. semester long design project). Development of an assessment tool for creative problem solving should capture all these aspects.

In general, creative problem solving (CPS) can be seen as a process to aid problem solvers in using creativity to achieve goals and increase the likelihood of enhancing creative performance[16]. The process of CPS is theorized to proceed through alternating divergent and convergent thinking[17]. Although process steps proceed in a sequential manner; empirical studies showed that while some people approached the steps in a linear fashion, some iterated, jumping back and forth[18]. These observed differences of natural CPS were related to individual differences in cognitive style[19.] For example, it was found that people who were innovators (on Kirton's adaptor-innovator) more frequently described their CPS process to be non-linear, more complex, random and contiguous. Their process contained more stages and multiple end points. Adaptors were more likely to go through the process in a linear, orderly, and targeted fashion with fewer stages[17].

Beyond an observable process, creativity can be described as a multifaceted ability found in various amounts in everyone[20]. Herman[21] argues that "Each person's experience of creativity is so unique and individual that no one can formulate a definition that fits everyone." Therefore, Klukken et al.[1] suggest that we should focus on identifying and developing an individual's creative potential. Prof. Carlos Santamarina of Georgia Tech who has written about and studied the teaching of creativity states that "There are skills that can be learned! Every student can be creative, better at problem solving and invention if they are aware of their own creativity and how to improve it."[22]

An instrument that has been used to loosely measure an individual's creative potential is the Herman Brain Dominance Instrument (HBDI)[28]. The scores and profiles from using the HBDI reveal four different ways of thinking and "knowing": A=analytical-logical-quantitative; B=sequential-organized-detailed; C=interpersonal-sensory-kinesthetic, and D=innovative-holistic-conceptual thinking. A longitudinal study at the University of Toledo conducted on first-year engineers from 1990-1993[24], revealed a decrease in the extent of B thinking (corresponding to plug-and-chug problem solving) and a corresponding increase in D thinking (creative) from tests conducted before and after the students went through a newly introduced first-year CPS course. The change may have been due to the very elastic nature of the brain that undergoes change with each use and can therefore result in thinking preference changes. Preferred thinking modes require less energy in the brain and are usually more enjoyable. Students who enjoyed the design experience in the first-year course may have therefore shifted their thinking preferences to D[24]. This and other studies, such as by Wilde[25], suggest that an increased level of creative activity in the engineering curriculum may indeed change the way a person thinks, thereby increasing their creative potential.

As evidenced in the examples above, CPS skills of students can be improved; however, it is very important to adopt the appropriate instruments not only for them to learn and deploy but also for instructors to measure their progress. In the following section, the repertoire of available creativity assessment instruments for various age groups is summarized.

Instrument Selection & Development Process

Our literature-based and on-line search uncovered 70 different creativity assessment instruments. These instruments were originally developed for different age groups (children of ages 3-6, elementary school students, middle to high school students, adults, etc.). Moreover, they varied in cost per instrument as well as available evidence on construct validity, testing reliability and utility. Therefore, a screening of available resources has been completed to reduce this universe of instruments in order to select an appropriate set for the purpose of this work. The following steps were performed to identify the most appropriate creativity assessment instruments.

- Initialization: An initial pool of creativity assessment tools was constructed based on the literature review and the on-line open source database of Center for Creative Learning (CCL, http://www.creativelearning.com). The database provides 72 commercial and non-commercial creativity indices with their information, and each index in the database is evaluated in four criteria (Manual Quality, Validity Evidence, Reliability Evidence, and Utility). Each criterion has four ordinal categories (Poor, Fair, Good, and Excellent). Table 1 presents brief definitions of these criteria, which were by and large adopted from Center for Creative Learning.

Table 1. Descriptions of Criteria for Tool Evaluation

Criteria	Description
Manual Quality	Is the information provided sufficient for administering the tool and appropriately presenting the result?
Validity Evidence	How much evidence on content validity is available? Is the tool measuring the intended construct?
Reliability Evidence	How much evidence on reliability is available?
Utility	How practical is the tool? How much does it take to complete?

After eliminating the tools with no evaluation data, and adding other tools from an additional literature review, 70 different creativity assessment tools were accumulated. Additional tools were evaluated with the same criteria and ordinal values. Table 2 provides a subset of the dataset.

Table 2. Data Structure of an Initial Creativity Assessment Tool Set

Title	Description				Criteria			
	Year	Subject	Purpose	Cost	Manual Quality	Validity Evidence	Reliability Evidence	Practicality
A Childhood Attitude Inventory for Problem Solving	1967	Upper Elementary	to assess the student's attitudes toward problem-solving	Contact Author	Poor	Poor	Fair	Fair
A Survey of Students Educational Talent and Skills (A.S.S.E.T.S.)	1986	Elementary	to identify children's gifts and talents	No data as to recent pricing	Fair	Poor	Poor	Fair
…	…	…	…	…	…	…	…	…

- 1st Screening: From the initial set of creativity assessment tools, we screened out tools that are targeted to college students. Eleven tools were selected as candidates for this study.
- Final Selection: The ordinal categories of the evaluation criteria were assigned to score values (i.e., poor: 0, fail: 1, good: 2, Excellent: 3), and a total criteria score of each tool was calculated by a sum of criteria scores. As a result, Creative Engineering Design Assessment, Purdue Creativity Test and Creative Behavior Inventory were selected as the most appropriate tools for creativity assessment for the subject pool that we intended to work with (See Appendix A).

Further, in the above mentioned screening and selection process, emphasis has been placed on the available instruments to assess the multiple dimensions of student learning (knowledge, interest, and strategic processing). For example, among the available instruments there was none that measured the knowledge of creative problem solving tools; therefore, that instrument had to be developed for this study. A few sample questions of this creativity tools knowledge inventory is provided in Appendix B.

After we identified possible instruments and created an instrument to measure the knowledge on CPS tools, we mapped expected behaviors and learning outcomes against the MDL components and stages. Table 3 provides sample items from the selected and/or developed instruments and illustrates where these items have been mapped within the MDL framework.

Table 3. Sample Overlay of the Instrument Items to the MDL Components and Stages

	Acclimation	Competency	Proficiency
Interest (Items Selected from Creative Behavior Inventory (CBI)[26]	Situational interest: Spontaneous, transitory, and environmentally activated interest that is associated with increased attention when a new topic is introduced **Participated in a craft workshop, club, or similar organization.**	Increased individual interest due to increased engagement in a domain **Kept a sketch book.**	Individual interest: long-term, deepening, personal connection to a domain, which in turn inspires further exploration of the domain **Won an award for a scientific project or paper.**
Knowledge (Items developed, see example in appendix B)	Limited and fragmented knowledge **Limited Knowledge on Brainstorming**	More cohesive domain knowledge principled in structure **Basic Knowledge on Biomimicry, Brainstorming and Idea Space**	Broad and deep knowledge **Working knowledge of at least five different creativity methods**
Strategic Processing (Items developed, see example in appendix & test problem)	Surface-level strategies: The implicit acceptance of information and memorization as isolated and unlinked facts **Only limited knowledge on when to use which creativity tool**	A mixture of surface- level and deep processing strategies **Knows the importance of choosing the right tool for the task**	Deep processing strategies: Applying isolated knowledge in problem solving procedures **Knows when to use which creativity tool and is aware of the issues that can limit creativity. Aware of pitfalls in CPS.**

Data Collection & Results

Subsequent to selection and development of various items corresponding to knowledge, interest and strategic processing, we administered the compiled instruments. The first instrument included the selected Creative Behavior Inventory (CBI)[26] questions, along with the creativity tools knowledge and strategic processing questions that our team has developed. The second instrument featured an engineering design problem inspired by a real problem – the problem of snow covered traffic lights causing traffic accidents due to low ambient heat generation by LED bulbs. Just like Creative Engineering Design Assessment (CEDA) by Charyton et al.[27], this instrument asked the subjects to design an artifact for a purpose. In our case, student subjects designed traffic lights that would use less energy without presenting with the barred vision problem, whereas in CEDA, subjects would be asked to design a noise making instrument using pre-defined pieces. The reason we have chosen to use the traffic light design problem is that we have a comprehensive set of solutions against which we can assess the generated designs in terms of their quality and novelty.

Sixty-four first year students in the College of Engineering at The Pennsylvania State University, who are currently taking engineering design courses, were targeted as the subject pool. The purpose and description of this study were presented to students, and subjects were not constrained in time for completing either of the instruments. Students were provided with a modest grade (0.5%) in return of their participation in an effort to ensure their full-engagement in the study. On average students worked about 15 minutes on their design before running out of new ideas for the engineering design task.

As per our stated goal of developing assessment instruments that will capture interest, knowledge and strategic processing, because we have deemed the MDL appropriate as a theoretical framework, we have aggregated responses to relevant questions in categories of interest, knowledge and strategic processing. Further, although performance in engineering design tasks can benefit from knowledge, interest and strategic processing, the domain of the presented problem can be a source of bias. In order to eliminate this possibility we have used a design task focusing on a product (traffic lights) that is familiar to all. Despite this fact, we have analyzed the generated feasible ideas under the "performance" heading.

The first step in our analysis focused on correlations among interest, knowledge, strategic processing and performance. A Pearson correlation analysis revealed low and insignificant correlations, shown in Table 4 below. Indeed, this is not surprising in that all study subjects are within the very first semester of their engineering education and have only recently confronted creative problem solving as part of their engineering design learning. The lack of correlations among performance, knowledge, and interest indicate that students are at the very beginning of the acclimation stage.

Table 4. Pearson Correlation Analysis Results

	Performance	Knowledge	Interest
Knowledge	0.016		
Interest	-0.085	0.115	
Strategic Processing	0.118	-0.014	0.050

The subsequent analyses featured comparisons between female and male students as well as students with a higher GPA to those with lower GPAs. We compared the CPS learning of male and female students using a t-test. Although we did not expect knowledge and strategic processing differences, we thought that there could be differences in interest as captured by the creative behavior inventory questions. There were 49 males and 15 females in the sample. Aggregate learning score weighted interest, knowledge, strategic processing and performance equally, using a scale of 0-4. While the mean learning score for males was lower than that of females' (1.429 vs. 1.527), the difference was not statistically significant (t-value= -1.02, p-value = 0.319). The plot of the individual learning scores for both males and females is presented below.

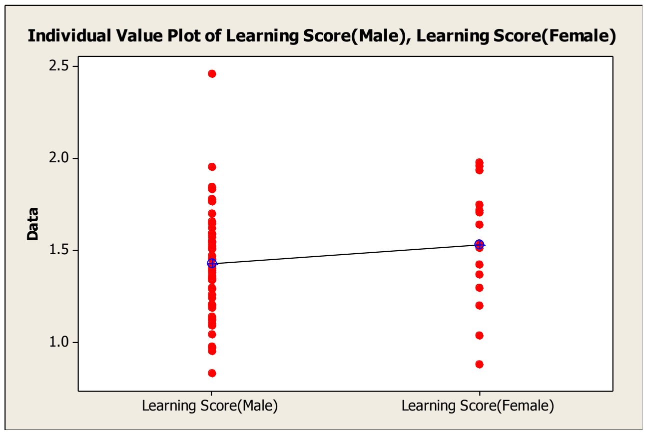

Figure 1. Learning score comparison across male and female subjects

We also compared the aggregate learning scores of students who have GPAs higher than 3.5 to those with lower ones. Subject counts, mean, standard deviation and error terms are shown in Table 5. This comparison revealed significant differences between these groups (*t*-value = 2.23, *p*-value = 0.032). The individual value plot and boxplot of the learning scores for these groups are shown in Figure 2. We note that we have not verified the GPAs of these students, and used them as they were self-reported. In general, however, these results are expected in that in general GPA might represent students' achievement and motivation; thus, our results reveal that students with higher GPAs showed also increased aggregate learning in creative problem solving.

Table 5. Comparison of Learning Scores

	N	Mean	StDev	SE Mean
Learning Score (GPA>3.5)	23	1.572	0.349	0.073
Learning Score (GPA<=3.5	41	1.385	0.270	0.042

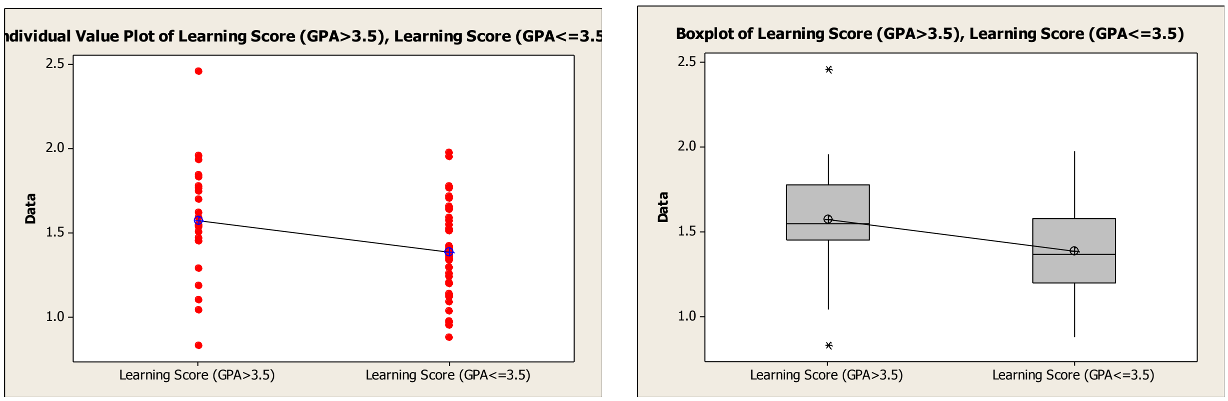

Figure 2. Learning Score Comparisons of GPA Groups

Discussion & Conclusions

In this paper, we have presented the rationale and the process of choosing and development of instruments to assess creative problem solving learning development in our students. In addition, we have analyzed more than 70 unique creativity focused assessment instruments designed specifically for various age groups, and covering various facets of creativity. Clearly, one of the very important benefits of the presented assessment framework is its flexibility in adopting instruments focusing on interest, knowledge and strategic processing and its easy adaption in different class standings. Just like for the case of creative problem solving, while there might exist many options for an area, for some there may not be any; or what is available may not have the desired validity and/or reliability evidence. Accordingly, development of new instruments may be necessary. In these settings, using the MDL approach as the framework will guide the focus of the assessment instrument selection and development as was done for the case presented.

Using the appropriate criteria to facilitate instrument selection is important. In this paper, we have focused on manual quality, validity and quality evidence from the literature, and utility (practicality) while comparing the available instruments. Validity and reliability evidence is specifically important; construct validity and reliability will provide the much needed clarity in construct definitions and reduce undue bias in implementation. Manual quality and practicality relate to available resources at the disposal of the team; for example, while there are instruments that have very well-designed manuals, they may be costly; thus, striking a balance in instrument costs and comprehensiveness of the assessment considering practicality is important. Again, this is an area of flexibility, where the set of instruments can be customized based on the needs and learning objectives set forth.

Future data collection using the instruments adopted and developed for creative problem solving will feature comparisons of (*i*) upper and lower classmen showing the progression, and (*ii*) various disciplinary domains for which the emphasis on creative problem solving might be different.

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Appendix

A. Selection of Creativity Assessment Instruments

Title	Description				Criteria				Total Score
	Year	Subject	Purpose	Cost	Manual Quality	Validity Evidence	Reliability Evidence	Practicality	
Creative Engineering Design Assessment	2008	Upper Undergraduate (Engineering)	To evaluate both problem solving and problem finding skills of students and to assess creativity specific to engineering design	Available on-line	Excellent	Excellent	Excellent	Good	11
Purdue Creativity Test	1960	Upper Undergraduate (Engineering)	To aid in the selection and placement of engineering personnel that need to produce original ideas to solve problems at work	$25	Excellent	Excellent	Excellent	Good	11
Khatena-Torrance Creative Perception Inventory	1998	Gr 4-12+adult	Uses an autobiographical/self-report model to provide the person an opportunity to describe how he/she functions in creative ways.	$57.65 per set	Good	Good	Excellent	Good	9
Barron-Welsh Art Scale	1987	Age 6-adult	To provide a non-language assessment of personality	$125	Good	Good	Good	Good	8
Khatena-Morse Multitalent Perception Inventory	1994	Grade 5 – adult	Uses a self-report approach to assessing leadership ability, visual and performing arts ability/music talent, art talent with a biographical inventory emphasis.	$56.60 per set	Good	Good	Good	Good	8
Pennsylvania Assessment of Creative Tendency	1973	Grades 5-adult	An attitude inventory to measure the creative tendencies of students. These are based on 3 assumptions: there is such a thing as a potential for creative output	Microfiche $15.00	Good	Good	Good	Fair	7
Sixteen Personality Factor Questionnaire (16PF), 5th Ed.	-	Age 16-adult	Designed to give complete coverage of personality in brief time.	Introductory Kit $33; Manual $30; 10 Select Questionnaires $30	Good	Fair	Good	Good	7
Test for Creative Thinking-Drawing Production	1996	Age 3 - adult	Designed to serve as a first rough, simple, and economic assessment of creative potential.	Complete test set $64; manual, $29; test forms: $0.70 each	Excellent	Poor	Good	Good	7
The Problem Solving Inventory	1988	Age 16-adult	Designed to assess an individual's perceptions of his or her own problem-solving behaviors and attitudes	Preview kit $42; 25 Item Booklets $30.30; Scoring Key $12.30	Good	Fair	Good	Good	7
Creative Behavior Inventory (CBI)	1979	Undergraduate and graduate students	Designed to assess engagement in creative acts across domains	Available on-line	Excellent	Excellent	Excellent	Good	11

B. Sample Items from the Creativity Tools Knowledge Test

Remaining items aim to identify how much knowledge / understanding / experience you have for each of the creative problem solving method listed. Please answer the following questions.

Please rate your knowledge on the following creative problem solving methods (**multiple choice is not available**).

- 1 (No Knowledge): you have not used or learned the method.
- 2 (Limited Knowledge): you have used or learned the method but you cannot explain the basic concept of the method.
- 3 (Basic Knowledge): you understand the basic concept of the method but you cannot use it without a manual.
- 4 (Competent Level Knowledge): you know the basic concept and application process of the method.
- 5 (Advance Knowledge): you fully understand the method and can freely extend / modify / revise the method according to your problems.

	1 (No Knowledge)	2 (Limited Knowledge)	3 (Basic Knowledge)	4 (Competent Knowledge)	5 (Advanced Knowledge)
Brainstorming*					
Method 6-3-5					
Idea Trigger					
Relevance Trees					
Idea Space					
The Gallery Method					
Biomimicry					
SCAMPER					
Morphological Chart					
De Bono’s Six Hats					
TRIZ					

*: **Note that descriptions of these methods are provided at the end of the questions.**