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How to provide better knowledge creation and diffusion in mechanical engineering: the DLSI as a vehicle

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ABSTRACT: The purpose of this study was twofold: to investigate the learning styles of students within the field of mechanical engineering (the main discipline for considering the generation of patent applications), and to determine the effectiveness of student learning styles as a means of predicting student performance. Different modalities of learning styles were investigated using a new dynamic learning style inventory (DSLI), which gave valid and reliable coverage of student learning styles and approaches to studying. Students' learning styles were compared and analysed using a two-sample study of 165 undergraduate and graduate mechanical engineering students from the University of Ljubljana, Slovenia, and 192 students from Cracow University of Technology, Kraków, Poland. Traditional lectures, teaching approaches and strategies do not allow active students to be more creative, whereas dynamic learning environments enhance students' performance and boost self-motivation.

INTRODUCTION

Mechanical engineering is one of the most important sectors in innovation-driven economies and contributes highly to the gross domestic product, to employment and value added economies. To date, the mechanical engineering sector has been characterised by a relatively low patent activity as one of the measures of national economy competitiveness [1]. Mechanical engineering technology is largely based on tacit knowledge, which embodies an individual's education, natural talent, experience and judgment [2].

Tacit knowledge is difficult to generate, and for a more in-depth understanding, it is necessary to differentiate between the various dimensions of knowledge as learning outcomes. Three categories of diversity that have important implications for teaching and learning are: a) learning styles; b) approaches to learning; and c) intellectual development [3]. Learning style as a component of the wider concept of personality should be used as a method to achieve the best learning results [4].

The use of a variety of teaching and learning approaches, methods and strategies has the potential to enhance learning and performance for a wider range of undergraduate and graduate students in a course. Each student can achieve more when the teacher or course designer matches educational context, content, process and methods to student personal learning styles.

To date, a dozen learning style inventories exist, but their reliability and validity in regard to a whole range of learning modes/dimensions are limited. For the purpose of this study, a new, self-developed dynamic learning style inventory (DSLI) was tested on a sample of mechanical engineering students from two countries, Poland and Slovenia. According to the World Economic Forum report, Poland is faced with the fact that even with a moderate availability of engineers, there is a significant lack of patents as an indicator of national competitiveness, while Slovenia decreased its number of engineers significantly, but its patent activity is adjudged to be good [1]. Engineering studies can reveal and develop creative capabilities among the students [5].

Learning Styles Modalities

Learning style is a generic concept that frequently includes cognitive styles, personality styles, emotional and sociological styles, sensory modes and different typologies [6]. According to the comparison of different learning styles and models, Hawk and Shah prepared a composite which consists of eight modalities: 1) learning orientation; 2) information processing; 3) understanding/thinking; 4) perceiving information; 5) physical and time orientation; 6) sociological orientation; 7) emotionality; and 8) environmental features [4].

Learning orientation and information processing is solid, and Kolb's learning style inventory (LSI), has been proved to be a valid and reliable enough instrument [7]. In regard to the dimension of thinking and perceiving information, Dunn and Dunn have developed LSIs, but there is only weak support for the validity and reliability of these instruments [8]. In addition, there is a new need for detecting cluster thinkers, especially, out of effective context mapping of cluster thinkers, which results in higher order cognitive level concepts [8]. Cognitive processes that were mentioned are crucial in the creative process. Research points to interesting links between how these processes function and creativity itself. Not always do these results provoke an enthusiastic look at this activity [5].

Besides cognitive factors, another important group is emotional and motivational factors, and the social environment that can trigger creative developments or effectively block it [5]. Modalities of physics and time, sociological, emotionality and environment are successfully covered by Dunn and Dunn's inventory; reliability and validity of them are judged to be moderate [9].

Considering the assumptions of general theoretical and definition comparability of the models, there are further complications in an attempt to find a universal approach. They are: 1) the scarcity of research supporting the validity and reliability of the instruments; 2) the cost of purchasing some of the instruments; 3) the use of class time to administer and interpret the instruments [4]; and 4) the use of different learning methods and strategies not just experiential learning after Kolb's cycle [7].

Against this background, the questions explored in this study are:

1. Do mechanical engineering students have enough inventive potential, considering learning styles mechanisms?
2. Are the learning styles significant predictors on student performance, measured with grade point average?

For this research, the authors used a new DSLI, which was administered at different learning and didactical approaches and methods and, it is capable of single or holistic treatment of different modalities.

METHOD

The sample, instrument, procedures and data analysis are described in the following sections.

Sample

The sample for this study consisted of undergraduate and graduate students enrolled in mechanical engineering courses from Cracow University of Technology, Poland, and the University of Ljubljana, Slovenia. With the permission of, and assistance from, the instructors who agreed to have their students participate in the study, a paper and pencil survey was distributed. Of the 365 enrolled students, 357 completed the survey entirely (2.2% missing values, n = 8). The number of respondents in this study fulfilled the requirements of a multiple regression model with eight independent variables in which at least 124 participants are needed to make confident assumptions about any observed relationships [10]. There were more male than female respondents (84% cf. 16%). Respondents were between the ages of 18 and 34 years, and more than half had taken undergraduate-level courses. Students from the University of Ljubljana represent 46.2% of these, while Cracow University of Technology students comprised 53.8%.

Instrumentation

The survey included questions on demographics, 94 questions on eight modes predictor variables with 34 subscales, and grade point average (GPA) as the cognitive variable. Demographic questions covered gender, age and course level. This study utilised an in-house-developed instrument. The instrument development involved all eight modules and three language versions (Slovene, English and Polish).

For assessment, a 6-point phrase completion scale was used as recommended by Achyar [11], and Hodge and Gillespie [12]. The new scale successfully substitutes and eliminates all limitations of the existing Likert scale. The intervals of the scale form a continuous type, from 0 (*very unlikely*) to 5 (*very likely*). It does not present the mean, but ensures the comparability of continuous responses and produces better assumptions of parametric statistics while avoiding bias [11][12].

The learning orientation and processing information scales were adopted from Kolb's learning style inventory developed by Kolb, in four subscales with three items each [7]. The scales of understanding/thinking and perceiving information were adopted from Felder and Silverman inventory [13]. There are three subscales with three items and two subscales with four items. A new subscale of cluster thinking was developed along the Felder-Silverman scale. The physical and time module is organised in nine subscales, four subscales with four items, two subscales with three items and three subscales with two items. This scale was adopted from Dunn and Dunn learning styles [9].

The sociological module is organised in three subscales with three items each. The emotionality scales was adopted from Dunn and Dunn as previous one and organised in six subscales with 14 items in total. The environmental scale was adopted from Dunn and Dunn and it is organised in seven subscales with two items each. A composite of learning styles consists of 94 items in total, and is ready for a single module use or for holistic measurement. A new survey demonstrates DSLI features. Three stages were involved in the instrument development process:

- Stage 1: slight modifications, such as wording changes were made to assure the suitability of items given the context of this study was within a multi-language (Slovene, Polish and English) survey setting.
- Stage 2: to ensure the content validity of the instrument, a content validity survey was conducted. Nine experts, including university professors and professionals with either research expertise or teaching experience in psychology, were invited to review the questions. The reviewers were asked to rate each item out of 134 initially developed and determine whether the item was adequate for these specific domains on a basis of three choices: essential, useful but not essential, and neither essential nor useful. Content validity ratio (CVR) was calculated based on the ratings from these nine experts. The threshold of CVR value to maintain an item for a case of nine reviewers is 0.65 [14]. Considering the small number of reviewers, it was decided to combine *essential* and *useful but not essential* into one option for CVR calculation. Items measuring similar concepts or with a CVR value lower than 0.65 were either removed or combined with other items. Wording changes were made based on the suggestions from the reviewers.
- Stage 3: the slightly revised items and combined items were sent back to the reviewers for a second-round rating to ensure they were adequate and necessary.

After item elimination and revision, there were 94 items in total (Table 2). The Cronbach's coefficient alpha values, calculated based on the sample of this study, indicated the developed instruments were reliable (Table 2). In cases of the multidimensionality or heterogeneousness of a test, Cronbach's alpha is not suitable as a reliability coefficient [15]. Therefore, the test-retest reliability was calculated by comparing the scores of 63 students who filled out the test during the survey pilot study (September 2014) and again during the second study (December 2014). The intraclass correlation coefficient (ICC) was used as a measure of ipsative stability as the stability of an individual's profile over time [16].

Table 2. Reliability information for subscales.

Module/dimension	Subscale	Number of items	Reliability Cronbach α	*ICC* (n = 63)
Learning orientation	Concrete (pragmatist)	3	0.71	0.84
	Abstract (theorist)	3	0.67	0.69
Processing information	Active (impulsive)	3	0.62	0.74
	Reflective	3	0.62	0.71
Understanding/thinking	Sequential	4	0.61	0.68
	Cluster	4	0.77	0.75
	Global	3	0.70	0.71
Perceiving information	Intuitive	3	0.66	0.71
	Sensing	3	0.73	0.73
Physical and time	Auditory	4	0.72	0.80
	Visual	4	0.64	0.72
	Tactile	3	0.78	0.83
	Kinesthetic	2	0.69	0.66
	Requires intake	2	0.75	0.71
	Does not require intake	2	0.84	0.83
	Evening - morning	3	0.83	0.75
	Afternoon	4	0.76	0.85
	Needs mobility	4	0.65	0.82
Sociological	Learning alone	2	0.61	0.66
	Peer oriented	3	0.78	0.82
	Authority figures present	3	0.62	0.82
Emotionality	Motivation - self	2	0.64	0.76
	Motivation - other	2	0.64	0.76
	Persistent	3	0.70	0.87
	Responsible	2	0.67	0.74
	Not very responsible	2	0.68	0.76
	Structure	3	0.68	0.74
Environmental	Sound - needs quiet	2	0.81	0.81
	Sound - acceptable	2	0.82	0.79
	Light - requires much light	2	0.76	0.81
	Light - requires low light	2	0.69	0.79
	Temperature	3	0.68	0.77
	Seating design - formal	2	0.85	0.78
	Seating design - informal	2	0.72	0.72

Procedure and Data Analysis

The researchers contacted instructors in Slovenia and Poland about their willingness to include their students in this survey. A paper and pencil method was utilised by interested instructors to distribute the survey. Students participated in the study during real-world classroom sessions throughout a study day. Administration of the survey was performed from March 2015 to April 2015 depending on the activity plan. A high response rate was obtained because of the direct presence of teachers or instructors and the method of survey administration.

Data analysis was conducted using SPSS software (v. 22; IBM, Armonk, NY). Descriptive analyses were conducted to present the student basic information and the average score of learning style variables. Multiple regression analyses were performed to investigate whether predictor variables significantly predict GPA. Multivariate analysis was conducted to find and confirm significant relationships between groups with an effect size. The measure of the effect size is partial eta (η) squared.

RESULTS

The first objective sought to describe the relationship between two groups of mechanical engineering students' learning styles, classified into thirty four subscales. Table 3 depicts the average scores on the subscales, where *M* - mean and *SD* - standard deviation.

Table 3. Average score for each subscale in learning orientation, processing information, thinking and perceiving information.

Learning style	Group	*M*	*SD*	Learning style	*M*	*SD*	N
Pragmatist	ME_SLO	3.93	0.71	Sequential	3.54	0.58	165
	ME_PL	3.72	0.74		3.44	0.62	192
	Total	3.82	0.73		3.49	0.61	357
Theorist	ME_SLO	3.44	0.71	Cluster	3.31	0.79	165
	ME_PL	3.43	0.68		3.35	0.74	192
	Total	3.44	0.69		3.33	0.76	357
Active	ME_SLO	2.78	0.91	Global	3.44	0.88	165
	ME_PL	2.59	1.05		3.66	0.73	192
	Total	2.68	0.99		3.56	0.81	357
Reflective	ME_SLO	2.91	1.23	Intuitive	2.04	0.97	165
	ME_PL	3.54	0.98		2.39	1.06	192
	Total	3.25	1.15		2.23	1.03	357
/	ME_SLO	/	/	Sensing	3.88	0.72	165
	ME_PL	/	/		4.06	0.69	192
	Total	/	/		3.98	0.71	357

Table 3 shows that mechanical engineering students are still concrete random learners where facts dominate. Surprisingly, the large number of reflective learners reveals that mechanical engineering enrols creative students, but convergent learning (pragmatist) still dominates. In contrast to existing learning styles, DSLI introduces cluster thinker, which involves approaching a decision from multiple perspectives (mental models) and reduces the handling of certainty/robustness. A cluster-thinking-style seems to prevent some obviously problematic behaviour relating to knowable impaired judgment.

Levene's test confirmed that the study sample did not violate the assumption of normality, which confirmed that the sample is normally distributed ($p > 0.05$). MANOVA tests of between-subject effect revealed significant differences in thinking (global) and perceiving information ($p < 0.05$) with small effect size (partial eta squared = 0.02). Slovene students are more pragmatic learners while Polish mechanical engineering students are more reflective, but the effect size is small in both cases (partial eta squared = 0.01)

An individual's characteristics and preferred ways of gathering, organising, and thinking about information are presented in Table 4. The prevailing learning style is kinaesthetic, but learning pathways are designed to allow learning alone and disable peer learning. A lack of self-motivation is detected, while the structured instruction and work are significant, especially, for Polish students; significant differences ($p < 0.05$) reveal the medium effect size (partial eta squared = 0.06).

Learning environment is an important factor for successful learning. Polish learners prefer sound (partial eta squared = 0.015), while Slovenian much light (partial eta squared = 0.01) and formal seating. The effect size partial eta squared was of a medium size (0.12). In general, mechanical engineering students prefer a comfortable environment, with acceptable noise (M = 2.93, SD = 1.3), bright light (M = 3.33, SD = 0.98), and elevated room temperature (M = 3.22, SD = 1.01), and formal seating (M = 3.48, SD = 1.2).

Table 4. Average score for each subscale in the learning styles module of physical and time, sociological and emotionality.

Learning style	Group	*M*	*SD*	Learning style	*M*	*SD*	N
Auditory	ME_SLO	3.07	0.72	Learning alone	3.19	0.99	165
	ME_PL	3.17	0.71		3.51	0.91	192
	Total	3.13	0.71		3.36	0.96	357
Visual	ME_SLO	3.32	0.61	Peer-oriented	3.40	0.75	165
	ME_PL	3.69	0.60		3.04	0.99	192
	Total	3.52	0.63		3.21	0.90	357
Tactile	ME_SLO	3.39	0.68	Authority present	3.05	0.79	165
	ME_PL	3.38	0.80		2.78	0.80	192
	Total	3.39	0.75		2.90	0.80	357
Kinaesthetic	ME_SLO	3.53	0.86	Motivation self	3.95	0.77	165
	ME_PL	3.89	0.68		3.58	0.83	192
	Total	3.72	0.79		3.75	0.82	357
Intake	ME_SLO	3.59	1.05	Motivation other	3.96	0.76	165
	ME_PL	2.76	1.28		4.07	0.71	192
	Total	3.14	1.25		4.01	0.74	357
No intake	ME_SLO	2.36	1.31	Persistent	3.63	0.66	165
	ME_PL	2.16	1.32		3.53	0.79	192
	Total	2.26	1.31		3.58	0.73	357
Evening- morning	ME_SLO	2.68	0.79	Responsible	3.66	0.89	165
	ME_PL	2.64	0.75		3.45	1.08	192
	Total	2.66	0.77		3.55	1.64	357
Afternoon	ME_SLO	2.91	1.05	Not responsible	1.70	1.01	165
	ME_PL	3.10	0.86		1.83	1.05	192
	Total	3.01	0.96		1.77	1.03	357
Needs mobility	ME_SLO	2.93	1.01	Structure	3.49	0.67	165
	ME_PL	3.08	0.88		3.82	0.67	192
	Total	3.01	0.94		3.67	0.69	357

Regression Analysis

The second objective sought to describe the relationship between students' learning styles and academic performance at the completion of their last semester of the study year. Multiple regression analysis was performed to see how much the independent variables can predict the student GPA.

The result revealed that the combination of the independent variables significantly predicts the student GPA (F (7, 34) = 7.55, $p < 0.001$). Approximately 37% of the variance in the student GPA was accounted for by the seven predictors. The explained variances were calculated using R^2 from path model where $R^2 = 0.02$ - a small impact, $R^2 = 0.13$ - a medium effect size, and $R^2 = 0.26$ presents a large effect size [17].

Table 5. Multiple regression of seven predictors of the student GPA.

Model	Unstandardised coefficients		Standardised coefficients			Collinearity statistics	
	B	SE_B	*Beta*	*t*	*Sig.*	Tolerance	VIF
(Constant)	8.01	0.30		26.517	0.00		
Active	-0.08	0.03	-0.11	-2.191	0.02	0.89	1.11
Pragmatist	-0.11	0.04	-0.12	-2.260	0.02	0.94	1.05
Visual	0.13	0.05	0.12	2.284	0.02	0.90	1.10
Learning alone	0.09	0.03	0.14	2.632	0.01	0.94	1.06
Not responsible	-0.14	0.03	-0.21	-3.901	0.00	0.88	1.13
Light much	-0.06	0.03	-0.10	-1.916	0.04	0.97	1.02
Seating informal	0.05	0.02	0.11	1.976	0.04	0.95	1.04

As shown in Table 5, there was no multicollinearity for the predictors with tolerances larger than 0.10 and VIFs smaller than 10. Variables were significant predictors in explaining the student GPA.

CONCLUSIONS

The research findings from the present study reveal the importance of learning styles in the design and performance of mechanical engineering courses.

Mechanical engineering students are still convergent thinkers, but a significant shift to sequential learning is detected with much more non-conformity and heuristic behaviour. Surprisingly, active learners seem to be frustrated with current methods and forms of work. Highly active experimentation individuals learn best when they can engage in such things as projects, homework or small group discussions. They dislike passive learning situation, such as lectures. These individuals tend to be extroverts. Learning by doing is crucial for the conversion of explicit knowledge to tacit knowledge. Pragmatists are expected to be less effective learners, as well as not being responsible learners. Visual and divergent learners have potential to be creative, but as peer-oriented learners. Peer-oriented learners are at the advantage in the transfer of tacit knowledge to tacit at the knowledge spiral conversion.

In this study, a significant lack of peer-oriented learners was detected, something that might be crucial in inventions and patents generation process. Students are given traditional lectures with a structure that reduces interactions and disables the kinaesthetic and tactile potential of students needed for externalisation of tacit knowledge to explicit. Mechanical engineering students who prefer an informal seating and learning environment might be successful at different active forms and methods of learning, e.g. blended learning, inquiry-based learning, distributed cognition, cognitive apprenticeship.

The practical implications of this study are that both teachers and course designers should pay more attention to students' learning styles, because teachers' guidance, structured material, and experimental and collaborative work matched with learning styles substantially contribute to students' learning achievements and innovativeness.

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