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Looking at Transdisciplinary Engineering Design Education through Bloom's Taxonomy*

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The shift of contemporary product design from being mono-disciplinary to transdisciplinary requires educational institutions to develop new educational methodologies to ensure their students are fully prepared for the new career and life-long challenges. This paper is a part of the study entitled Transdisciplinary Design Education for Engineering Undergraduates, which goal is to enhance engineering education by developing transdisciplinary teaching methodology and establishing a common engineering design process. This paper presents detailed results from the cognitive game task, based on the Bloom's Taxonomy Cognitive Domain and a general engineering design process, developed to access the design thinking of engineers. The general design process and its stages, application of Bloom's Taxonomy and a list of action verbs, and transdisciplinary teaching approach are discussed.

Keywords: engineering design education, transdisciplinary design, engineering design process, Bloom's Taxonomy

1. Introduction

In our previous work we discussed the new transdisciplinary nature of contemporary industrial product design and, as a result of which, a need for reforming and enhancing engineering design education in line with industrial demands [1, 2]. Rapid development of science and technology lead to advancement and expansion of the engineering field, making engineering products such as automobiles or industrial machines more complex. Today, design and development of such integrated products require a collaboration of specialists from multiple disciplines, working in so called transdisciplinary teams, who share a common understanding of design processes. A line of empirical studies in industry revealed several core similarities between multiple engineering disciplines, showing that engineers in each discipline follow similar design stages and recognize core cognitive processes related to design but address them in different terms [3–6]. These results show that industrial product design shifted from mono- to transdisciplinary. However, research in engineering education shows that engineering design curricula still remain very discipline-specific, rarely include transdisciplinary knowledge from other disciplines, and do not often account for professional and cognitive development in students [7, 8]. This in turn is reflected in contemporary industrial employers claiming that recent graduates lack sufficient technical knowledge of transdisciplinary design as well as professional skills such as communication, creativity, problem-solving and teamwork [9, 10].

New times requires new ways of thinking and multilateral abilities to succeed in contemporary workplace. This is why post-secondary institutions have to adapt to contemporary industrial demands by enhancing engineering curricula with the new transdisciplinary methodologies and focusing equally on the development of both technical and professional skills in students [11–13]. In particular, the following questions should be addressed:

- What should be done to better prepare students for successful entrance and performance in the contemporary workplace?
- What methodology can be used for teaching transdisciplinary design with focus on cognitive and professional development in students?

2. Developing transdisciplinary approach

Transdisciplinarity can be defined in various ways, however one of the most inclusive definitions was provided by Ertas et al., who defined transdisciplinarity as "the integrated use of tools, techniques, and methods from various disciplines" that exists "simultaneously between disciplines, across different disciplines, and beyond all disciplines" [3, 14, 15]. In order to properly enhance engineering curriculum, it is essential to understand what and how is currently being taught and to apply the appropriate transdisciplinary teaching methodology. In other words, it is important to understand how engineering professors teach, what they think about engineering design and transdisciplinarity, and what

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types of design activities are included in the design process. Also, it is important to account for other factors such as employers' demands, educational approaches, psychological perspectives, benchmarking with other institutions, etc. This paper a part of a series from the study entitled *Transdisciplinary Design Education for Engineering Undergraduates*, which goals are to, first, review the current engineering design education across engineering disciplines and, then, develop a common engineering design process applicable in all disciplines and a methodology for teaching transdisciplinary engineering design.

Educational Framework: As mentioned above, contemporary product design has become transdisciplinary and this new reality should be properly addressed in engineering education by developing and adapting educational curricula in line with industrial demands. In the past, we discovered that very few studies on enhancing engineering education included transdisciplinary analysis of all engineering disciplines. Also, they rarely covered any cognitive attributes and almost never the whole cognitive domain [16, 17]. In order to incorporate all engineering disciplines and account for the full range of cognitive attributes, we performed a transdisciplinary study. In order to develop a suitable methodology for teaching transdisciplinary engineering design, we incorporated results from industrial and education research in engineering design, teaching methods and psychological perspectives on design. These factors were included in our education framework—Transdisciplinary Engineering Design Education Framework (TEDEF), which serves as a guide for our study and the development of the transdisciplinary teaching methodology [1].

Transdisciplinary Approach: In our study, we aim to establish a common engineering design process by looking at similarities between disciplines, in particular how engineers think about the design process. While searching for a way to provide a common foundation for the development of transdisciplinary education and a common language between disciplines, we discovered a methodology named Bloom's Taxonomy. Bloom's Taxonomy, a learning taxonomy, comprised of three domains—cognitive, affective, and psychomotor [18, 19]. It was chosen for this study because of its unique education features: relation to cognitive abilities, applicability for teaching in any discipline or domain, use in curriculum design and learning outcomes, and serving as a common language to compare and discuss different subject areas or explore how different subject can overlap [20, 21]. These make Bloom's Taxonomy a perfect teaching tool for transdisciplinary education. In addition, Bloom's Taxonomy is recommended by the CDIO initiative, implemented in more than 100 engineering schools across the globe, whose goal is to provide a common ground and enhancement strategy for engineering education [22].

In this study, we focus on the Cognitive Domain of Bloom's Taxonomy, which is related to conscious cognitive and intellectual activity [23] and consists of six cognitive levels: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. Based on Bloom's Taxonomy Cognitive Domain, we developed a tool designed to access the design thinking of engineers—the cognitive game task, which can be performed by engineers from any discipline and department and is linked to the engineering design process [2]. The game task serves the following purposes:

1. To collect the names of design process stages, which are used in each engineering discipline, to identify the common ones;
2. To identify the number and variety of design activities performed at each design stage;
3. To create an engineering design ontology to scientifically establish the common engineering design process across all disciplines, accounting for the cognitive design activity.

Methodology: A part of the TEDEF framework includes an extensive review and transdisciplinary analysis of the engineering design courses, review of regulatory requirements, and interviews with the engineering professors from multiple engineering disciplines. 34 professors from 8 disciplines from the Faculty of Engineering at the University of Alberta who have taught design courses with the heaviest design component as per Canadian Engineering Accreditation Board (CEAB) curriculum maps 2016 participated in the study [2, 24]. They have also shared their course materials. There were total of 46 design courses with the heaviest design component identified at the Faculty, out of which 23 were included in the study. There were four 2nd year courses, five 3rd year courses, and twenty-one 4th year courses, out of which 7 were defined as capstone courses. Participants were invited for a 1-hour interview, where they were asked about the course they teach and their design teaching methodology. Then, they were asked to do the cognitive game task and provide their feedback about it.

The cognitive game task was developed based on action verbs from the Cognitive Domain of the original Bloom's Taxonomy and the 6-stage general design process. The design stages are called *Planning (PL), Concept Development (CD), System-Level Design (SLD), Detailed Design (DD), Implementation and Testing (IT), and Production (PR).* These stages were used because they were found to be similar to the most common design stages identified in industrial studies on the general transdisciplinary design processes [3-6] as well as current design process practices at the University of Alberta, and were recommended by Ulrich and Eppinger for industrial product design [25].

Figure 1 shows the cognitive game task user board, which is specifically designed for this task. The board has design process presented at the top, which starts with an *initial idea* and ends with a *final product*. The design process is divided into 6 stages (columns). Each column is named with a design process stage and has an empty window below.

Bloom's Taxonomy consists of 3 domains of learning, which are further divided into different sub-domains or levels depending on the type of mental/learning activities that takes place on each level. Each sub-domain has its own list of actions verbs that are used to develop learning outcomes or assessment tasks. As stated earlier, the cognitive game task was developed using the Cognitive Domain. As shown in Table 1, from each of the 6 levels of the Cognitive domain 7 unique action verbs were selected based on their relation to engineering design activities [26]. There were 42 unique action verbs used in the game task. During the pilot trials, 12 unique action verbs were taken from each cognitive level at first, however, larger number of verbs caused significant level of fatigue in participants and lead to the decrease in the performance success rates, so the number of verbs was reduces from 72 to 42.

The Cognitive Game Task: The game task has 3 steps. First, all participants are given a game board with 6 general design stages placed along an arrow representing the design process and corresponding

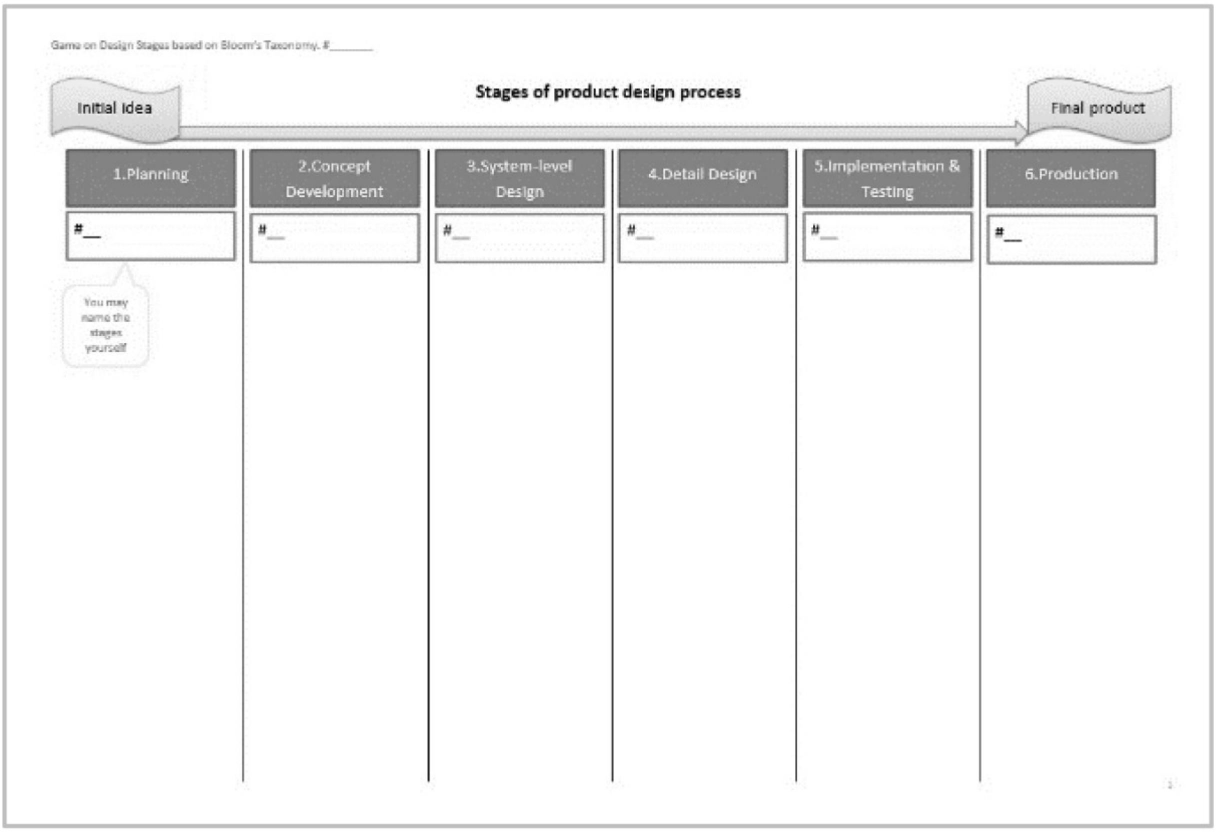

Fig. 1. The cognitive game task user board.

Table 1. The action verbs of the Cognitive Domain of Bloom's Taxonomy used in the study

Cognitive Domain	**Action Verbs**
Knowledge (Kn)	Define, Describe, Identify, List, Name, Order, Recognize
Comprehension (Cm)	Classify, Discuss, Distinguish, Estimate, Extend, Indicate, Review
Application (Ap)	Apply, Choose, Compute, Illustrate, Modify, Practice, Solve
Analysis (An)	Analyse, Calculate, Compare, Criticize, Infer, Model, Test
Synthesis (Sn)	Combine, Create, Design, Develop, Generate, Prepare, Synthesize
Evaluation (Ev)	Conclude, Defend, Evaluate, Explain, Justify, Interpret, Predict

empty columns for each stage. All participants are then given an opportunity to rename the proposed stages as per their discipline or they can use the stages provided. Then, all participants are given 42 stickers with randomly mixed action verbs. They are asked to fill up all stickers with a noun related to the design process from their engineering discipline, forming the design activities. For example, *to define* "problem". Lastly, participants have to place all stickers, or design activities, into columns with the corresponding 6 design stages based on "*what they think is the best place for those activities to happen in the design process*". While placing the stickers into the columns, all participants have to think about the design process in their discipline. Participants must place each sticker in one column only and not into two or more.

Preliminary Results Review: Previously, we discussed the second purpose of the game task and the link between Bloom's Taxonomy and the general engineering design process. In particular, we examined how Bloom's Taxonomy Cognitive Domain was mapped along the design process. The preliminary results for all departments showed the following [2]:

1. The majority of design activities fall on the beginning of the design process. The first 3 design stages are the most critical as more activities happen here, especially at the Concept Development stage, which can affect the rest of the design process and result in iterations.
2. The cognitive load, or the amount of design activities necessary to carry the product design, differs from stage to stage and gradually shifts from lower to higher levels of thinking along the design process, i.e. from Knowledge to Evaluation. But all cognitive levels were in use at each design stage.
3. Different cognitive levels are significant at different stages depending on the purpose of the stage and design activities to be performed.

This showed the importance of the cognitive activity with regards to the engineering design activity and linked Bloom's Taxonomy to engineering design process.

Current Objectives: The next step is to explore in greater details the role and application of Bloom's Taxonomy in transdisciplinary engineering design education. This paper will provide a more detailed analysis of the game task, discuss the first purpose of the game and the departmental breakdown of the results, and review the participants' feedback. In addition, Bloom's Taxonomy and its role in transdisciplinary engineering design education will be discussed.

3. Results and discussion

3.1 Design process stage names

The first purpose of the cognitive game task was to collect the names of design process stages, which are used in each engineering discipline, to identify the common ones. This was done to establish a common base of reference with regards to the design process stage names across all disciplines. During the game task, engineering professors were asked to rename the suggested design stages as per their disciplines or they could choose to use the provided names from the general 6-stage design process.

To analyze the results, we used the frequency count of design stage names. The input Excel file, which contained 6 design stages and suggested design stage names from 34 participants, was analyzed using a Python's library called "pandas" [27]. Using the custom developed algorithms, we first analyzed the stages given by researchers and suggested by participants and then calculated how many times the given and suggested stage names appeared in each stage. At the end, the final output file contained a table with the all design stage names used by participants at each stage their respective frequency counts.

The results showed that, surprisingly, the names given by participants who renamed the stages were different and almost never repeated even within the same discipline. However, as shown in Table 2, the number of times when professors chose to use the suggested design stage names from the general design process from the game board was significantly high. This supports the assumption that the stage names from the suggested general design process are indeed very common among all engineering disciplines and are suitable for the use as a common base of reference when discussing the transdisciplinary design process.

3.2 Bloom's Taxonomy cognitive domain in different engineering departments

The second purpose of the game was to identify the number and variety of design activities performed at each design process stage. Referring to the preliminary results shown in Table 3 [2], the number of

Table 2. The preference rate of the provided design stage names from the suggested general design process

Stage name	Times a stage name was used out of 34
Planning (PL)	12
Concept Development (CD)	21
System-Level Design (SLD)	20
Detailed Design (DD)	23
Implementation & Testing (IT)	17
Production (PR)	20

Table 3. The total distribution of the Cognitive Domain action verbs at each design stage for all departments

Design stages/Cognitive Domain	PL	CD	SLD	DD	IT	PR
Knowledge	105	52	24	19	22	16
Comprehension	39	67	35	41	41	15
Application	23	53	49	68	35	9
Analysis	13	49	55	44	73	4
Synthesis	35	61	41	51	22	28
Evaluation	17	55	41	35	61	29
Total	232	337	245	258	254	101

design activities (i.e. stickers with action verbs from the Cognitive Domain and design related nouns) were used to determine the length of each design stage. As discussed above, during the preliminary analysis, we examined how Bloom's Taxonomy is mapped along the design process and saw how design activities are distributed for all departments at once.

After the preliminary analysis, we took a deeper look at the results and examined the departmental differences. Based on the chi-square test for the contingency table results, there is a clear evidence that the distribution of verbs across the design stages is non-homogenous in all cognitive domains (value = 280. 02924, df = 25, p-value < 0.0001). Same holds true when each domain is evaluated individually (p-value < 0.0001). In addition, based on the chi-square goodness-of-fit test, there is a strong evidence that the distribution of verbs is not uniform across the design stages (value = 123.24107, df = 5, p-value < 0.0001). These suggest that the differences between engineering design stages and between cognitive levels are not a matter of coincidence, but they reflect the natural connection between engineering design activity and cognitive design activity.

Given these results, we further investigated how Bloom's Taxonomy Cognitive Domain is applied in each engineering department. Fig. 2 shows the total distribution of the Cognitive Domain along the design process. Figs. 3 to 6 show the results for the Chemical and Materials Engineering Department, Electrical and Computer Engineering Department, Civil Engineering Department, and Mechanical Engineering Department respectively.

As shown in Figs. 3–6, all departments, except for the Civil Engineering, proportionally perform similar amount of design activities at each stage. However, the differences between them should be highlighted. In Chemical and Mechanical Departments, most of design activities fall into the Conceptual Design stage, in Electrical Department it falls into both Concept Development and Implementation and Testing stages, and in Civil it falls into the Detailed Design stage. This suggests that different departments follow different design pro-

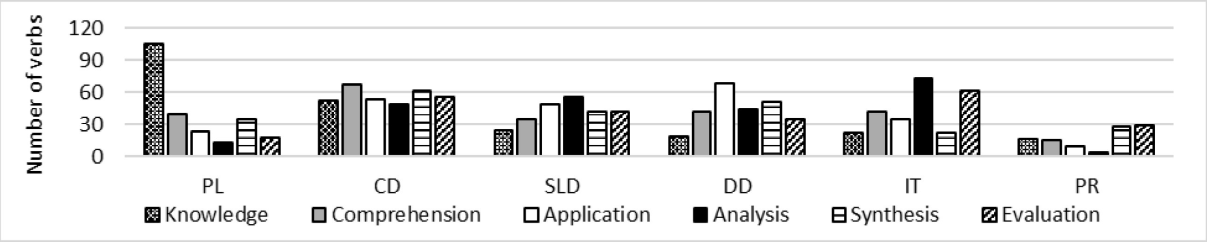

Fig. 2. Total distribution of the Cognitive Domain along the design process for all departments.

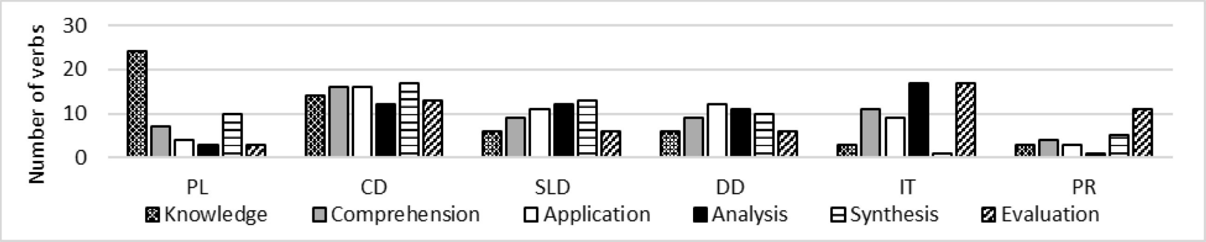

Fig. 3. Distribution of verbs along the design process in the Chemical and Materials Engineering Department.

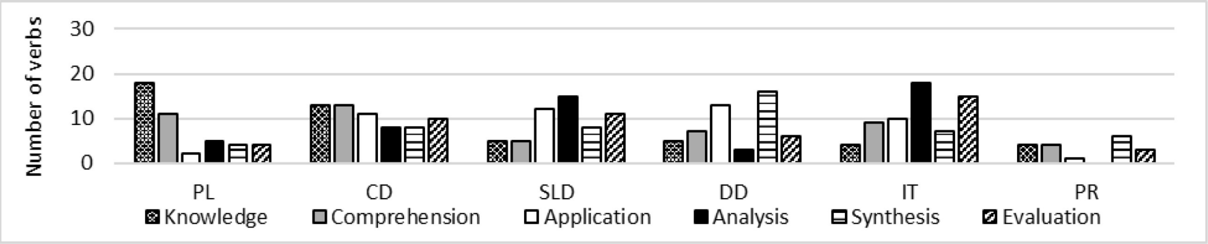

Fig. 4. Distribution of verbs along the design process in the Electrical and Computer Engineering Department.

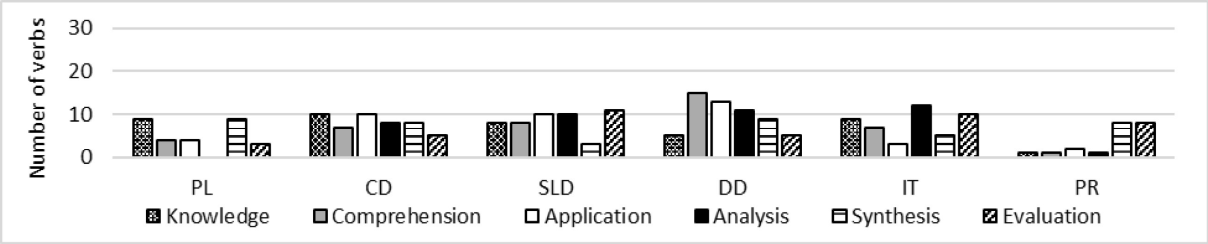

Fig. 5. Distribution of verbs along the design process in the Civil and Environmental Engineering Department.

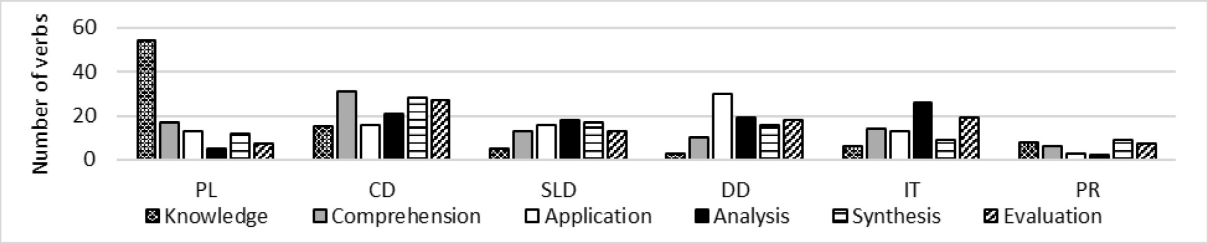

Fig. 6. Distribution of verbs along the design process in the Mechanical Engineering Department.

cesses and perform different number of tasks at each stage depending on the type of systems and produce they work with.

At Planning stage, the Knowledge level prevails in Chemical, Electrical and Mechanical Departments, while both Knowledge and Synthesis levels prevail in Civil Engineering Department. At Concept Development stage, Comprehension level peaks in Chemical and Mechanical Departments, while both Comprehension and Knowledge peak in Electrical, and both Knowledge and Application peak in Civil Department.

At System-Level Design stage, Synthesis peaks in Chemical department followed by Analysis, while Analysis dominates in Electrical and Mechanical Departments. Civil Department is dominated by Application, Analysis and Evaluation at the same time. At Detailed Design stage, Application peaks in both Chemical and Mechanical Departments, while in Electrical Department Synthesis and Comprehension clearly dominate. In Civil department, Detailed Design stage is dominated by the Comprehension. At Implementation and Testing stage, Analysis dominates in Electrical, Civil and Mechanical Departments, while in Chemical Department both Analysis an Evaluation peak at the same time.

Lastly, at Production stage, relatively low number of activities is performed in each department, which suggests that departments spend lesser amount of time on covering the production and manufacturing processes. Clearly, Evaluation dominates in Chemical Department, Synthesis in Electrical and Mechanical Departments, and both Synthesis and Evaluation peak in Civil. These findings again point out to the differences between engineering disciplines and departments in terms of the design products they design and the way they approach them cognitively and practically.

These results suggest that in principle all disciplines follow the same general design process but differ in terms of the length of each design stage. The number of design activities at each stage may be used as a function of time taken to compete each design stage. These results suggest that in different disciplines the stages of the design process vary in length depending on the type of product and required design process activities. In addition, Civil, Mining and Petroleum engineering department is slightly different from others because their process is more or less even in terms of the stage workload. However, all departments dedicate significant amount of time to the middle of the process and not so much at Production stage.

Given the novelty of this study, its limitations should be considered, in particular the use of the original Bloom's Taxonomy, the limited set of action verbs, and pre-defined number of design stages. In addition, the departmental breakdown depends on the number of participant from each department. Since Mechanical Department had the highest number of participants, there were the higher number of verbs. In future work it would be interesting to replicate this study with equal number of professors from each department, as well as with students, use the revised Bloom's Taxonomy, increase the number of action verbs to manipulate the cognitive levels, and see the difference in responses between different engineering departments. It would also be interesting to replicate this cognitive game task with industrial designers to investigate their design thinking.

3.3 Game task feedback

After the game task was over, all participants were debriefed and asked to answer 4 questions to provide the feedback. The results are show in Fig. 7. More than half of all participants rated the game as easy, however, a significant number of participants felt that that game was difficult. One of the possible reason for such rating is that some engineering professors had difficulty to come up with discipline-specific nouns and chose to use the general nouns related to design. When it comes to the decision for placing stickers, in particular design stages, participants relied more on the professional experience followed by the teaching experience. However, while choosing the design-related nouns, participants used their teaching experience followed by the research experience. Lastly, participants reported that their nouns primarily came from their teaching experience, followed by professional and research experience. This suggests that engineering professors strongly rely on their professional experience in engineering design and only then on their teaching and research experiences, which often happen simultaneously. These results strongly suggest that professors who are offered to teach engineering design courses are more likely to perform better if they first experienced the industrial work.

3.4 Cognitive domain: a deeper look

Since we established that Bloom's Taxonomy is strongly linked to design process, we took a step further and attempted to make Bloom's Taxonomy even more suitable for the transdisciplinary education (in any discipline). Bloom's Taxonomy Cognitive Domain has been widely applied in many educational institutions over the decades given its unique educational features discussed above. However, with time Taxonomy has been revised by Bloom's followers and updated by educational institutions themselves to fit their academic needs [28]. Today, there are multiple sources available in print and online that provide the descriptions of the Cognitive domain, definitions of the 6 cognitive levels, and lists of actions verbs. This, in turn, imposes a difficulty for the educators and post-secondary institutions to achieve the consensus if

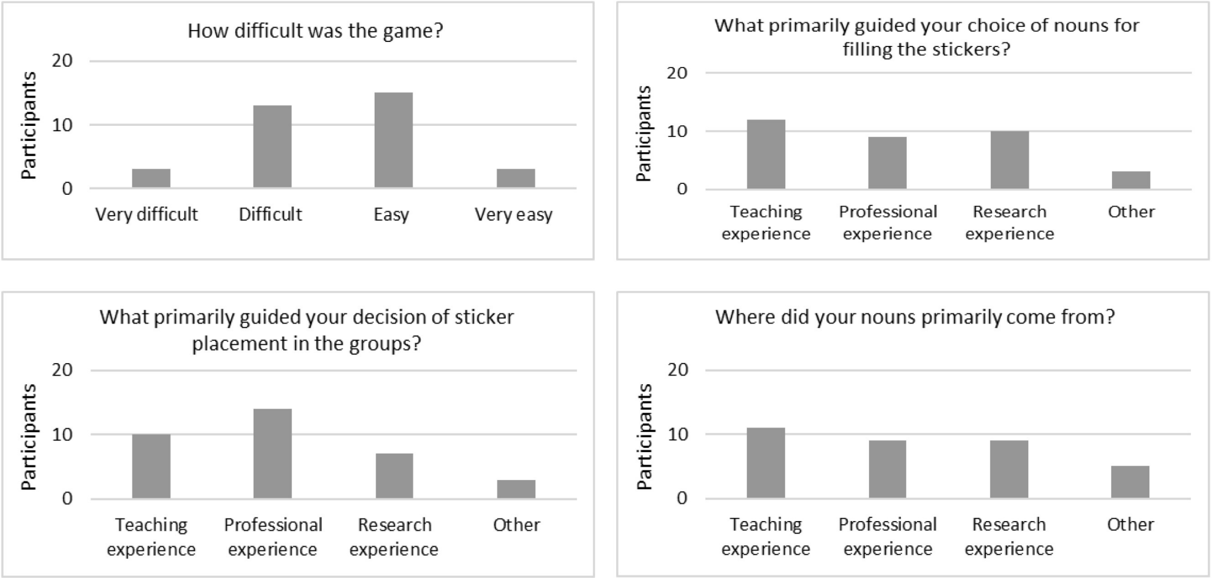

Fig. 7. The feedback survey results.

they are to develop a common or transdisciplinary courses due to the differences between different lists of action verbs. To overcome this difficulty, we attempted to derive a common foundation for the Cognitive Domain of Bloom's Taxonomy in the form of a common list of action verbs using the scientific tools.

First, we established the semantic similarity between the definitions of the cognitive levels used in different sources. The third purpose of the cognitive game task was to gather the nouns for the development of the Transdisciplinary Engineering Design Education Ontology (TEDEO) to prove the common design process and trace discipline specific processes, which is discussed in more details in [29]. The TEDEO ontology is developed using semantic similarity approach based on data analytics. One of the advantages of this approach is the ability to semantically compare words and their meaningful relations to each other, with and without the context. This approach not only allows to build the ontologies but also to compare the definitions and establish the meaningful or semantic relations between them.

Table 4. The semantic similarity between cognitive levels based on their definitions from list source 1

Cognitive levels	Kn1	Cm1	Ap1	An1	Sn1	Ev1
Kn1	1					
Cm1	0.3	1				
Ap1	0.3	0.3	1			
An1	0.3	0.3	0.3	1		
Sn1	0.2	0.2	0.2	0.6	1	
Ev1	0.2	0.2	0.2	0.7	0.2	1

Table 5. The semantic similarity between cognitive levels based on their definitions from list source 2

Cognitive levels	Kn2	Cm2	Ap2	An2	Sn2	Ev2
Kn2	1					
Cm2	0.2	1				
Ap2	0.6	0.5	1			
An2	0.7	0.8	0.8	1		
Sn2	0.3	0.3	0.7	0.3	1	
Ev2	0.3	0.2	0.3	0.2	0.4	1

We collected 21 most common lists of action verbs from Bloom's Taxonomy Cognitive Domain with the definitions of the cognitive levels that are most commonly used by educational developers or schools and are available online [23, 26, 30–42]. Using the Align, Disambiguate and Walk (ADW) unified approach for measuring the semantic similarity discussed in [43], we compared the definitions of the 6 cognitive levels from two (2) randomly selected lists of action verbs to establish a semantic similarity between them and understand how each level relates to one another.

Tables 4 and 5 provide the correlation coefficients of semantic relations between the 6 cognitive levels based on their definitions for 2 different lists of action verbs. Tables 6 and 7 provide the actual definitions used for the calculations of these semantic relations, which are stated in Tables 4 and 5 respectively. Table 8 shows the semantic similarity relations between definitions of the cognitive levels between two lists described in Table 6 and 7. The correlation coefficient ranges from 0 (unrelated) to 1 (same or synonymous).

As can be seen from Tables 6 and 7, the definitions of the cognitive levels are synonymous, but use somewhat different words to define them. The results in Table 4 should be interpreted as follows: Knowledge level (Kn1) has the strongest relation with itself (its own definition) and weakest with Synthesis level (Sn1), which highlights their semantic difference from one another. From Tables 4 and 5 it can be seen that all cognitive levels have the

Table 6. The list of definitions for the 6 levels of Bloom's Taxonomy Cognitive Domain from list source 1 [26]

Cognitive Levels	Definitions
Kn1	Remember previously learned information
Cm1	Demonstrate an understanding of the facts
Ap1	Apply knowledge to actual situations
An1	Break down objects or ideas into simpler parts and find evidence to support generalizations
Sn1	Compile component ideas into a new whole or propose alternative solutions
Ev1	Make and defend judgments based on internal evidence or external criteria

Table 7. The list of definitions for the 6 levels of Bloom's Taxonomy Cognitive Domain from list source 2 [30]

Cognitive Levels	Definitions
Kn2	Recall information
Cm2	Understand the meaning, paraphrase a concept
Ap2	Use the information or concept in a new situation
An2	Break information or concepts into parts to understand it more fully
Sn2	Put ideas together to form something new
Ev2	Make judgments about value

Table 8. The semantic similarity correlation between cognitive levels based on their definitions from both sources

Cognitive levels	Kn1	Cm1	Ap1	An1	Sn1	Ev1
Kn2	0.9					
Cm2		0.5				
Ap2			0.8			
An2				0.7		
Sn2					0.9	
Ev2						0.8

strongest semantic relation with regards to themselves but different with regards to other levels.

As shown in Table 8, the semantic relation between the Knowledge level definitions 1 and 2 from two sources is 0.9, which suggests that the semantic relation between two lists' definitions is significantly strong and two definitions are very similar or nearly identical in meaning. From Table 8, it is evident that, despite that the provided definitions of the cognitive levels in each source are synonymous but are formulated using different words, the definitions from two different sources show significantly strong semantic similarity. This suggests that the definitions of the cognitive levels in different lists and sources are on the basic level synonymous and semantically related.

Given the above results, it is now possible to derive the common list of action verbs for the Cognitive Domain. To derive the common list of action verbs, we performed a frequency analysis, using the 21 most common lists. Each list had a different number of action verbs at each cognitive level compared to the other lists and different number of verbs at each level in each list. The verbs were input from all sources into the table with 6 cognitive levels. This was done by scanning using Python by simply opening the file and reading line by line to obtain all verbs from each cognitive level. Then, all verbs were converted to only lower case letters and went through a lemmatization process, which was done via utilization of a Python's library called NLTK that has an interface similar to WordNet (a lexical database for the English language) [44]. Any sentences or verb-noun pairings were excluded. After pre-processing was done, the program counted verbs from each cognitive level and established how many time a verb was repeated. Finally, all verbs frequencies were sorted in descending order. The verbs were ordered by the frequency in which they appear in all lists (the maximum value is 21 since there were 21 lists) and their frequency number is displayed together with their names. Please, see the full common list of action verbs used for the Cognitive Domain in Table 9 in the Appendix. Application domain, followed by Analysis and Synthesis, has the highest number of verbs suggesting that, depending on the context of the discipline, different activities can be used compared to other levels that have more or less the same activities. This common list of action verbs suggests the most commonly used verbs in various sources. It is recommended to use the verbs from the common list that appear more than 5 times for the general or transdisciplinary educational purposes and all frequency verbs if needed for additional or specific purposes.

The cognitive game task based on Bloom's Taxonomy helped to collect a database of design activities to establish and empirically prove the common engineering design process applicable in all engineering disciplines with the cognitive foundations behind it. But most importantly, this task helped to establish the link between Bloom's Taxonomy and the transdisciplinary engineering design process and investigate how the cognitive activity is applied at each design stage and is distributed along the design process. The verbs and nouns that constitute the design activities represented the direction of the designer's thinking and the objects that operate in those thoughts respectively. In addition, the established semantic link between cognitive levels of Bloom's Taxonomy allowed the development of the common list of action verbs of the Cognitive Domain. This list is the most extensive list of actions verbs of the Cognitive Domain as of today and is applicable for any education discipline.

4. Conclusions

The need for transdisciplinary methodology for teaching engineering design served as a motivation for this study. The objectives of this study were to research and investigate the approach, which could help educators better prepare future engineering graduates for successful transition intro industry today and develop a methodology for teaching transdisciplinarity engineering design. In particular, this study focused on establishing the general engineering design process and developing a transdisciplinary teaching approach. This paper presented the empirical results of the innovative approach—the cognitive game task based on Bloom's Taxonomy—designed to access the design thinking of engineers and industrial designers. It also discussed the established general engineering design process and provided deeper insights on the Cognitive Domain of Bloom's Taxonomy.

The results presented in this paper should be considered for the development, re-design or enhancement of transdisciplinary engineering and discipline-specific design courses. The general design process, especially when paired with Bloom's

Taxonomy, is recommended for teaching design in the introductory design courses or in any engineering discipline as it provides a common educational and cognitive foundations for design thinking. The common list of action verbs of the Cognitive Domain is suggested for use when designing course learning outcomes, learning activities and assessments. The cognitive game task can also be implemented in design courses as a practice exercise to allow students to explore their own design thinking, design process and method.

The common engineering design process, the cognitive game task, and the common list of action verbs from Bloom's Taxonomy Cognitive Domain together constitute the methodology for teaching transdisciplinary engineering design. To further investigate the effect and practical implications of this approach, these results shall be tested and piloted in few engineering design courses at the University of Alberta. The results are also to be incorporated and considered in the design and development of the common first-year engineering design course, which is the next step of the TEDEF framework and to be discussed in future work.

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Appendix

Table 9. General list of action verbs of Bloom's Taxonomy Cognitive domain derived from 21 most popular lists

Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
list—20	explain—19	demonstrate—18	compare—20	design—20	judge—21
name—18	describe—18	use—17	contrast—19	create—19	appraise—17
define—16	discuss—18	apply—17	distinguish—17	formulate—18	evaluate—17
repeat—15	paraphrase—14	solve—17	analyze—17	plan—17	support—15
state—15	restate—13	illustrate—15	differentiate—13	compose—16	assess—15
label—14	summarize—13	dramatize—13	separate—12	construct—16	select—14
recall—14	translate—10	practise—13	examine—12	develop—13	justify—14
identify—13	convert—10	employ—12	diagram—10	combine—12	compare—13
reproduce—12	review—10	operate—12	infer—10	assemble—12	rate—13
describe—12	express—10	sketch—11	categorize—9	propose—11	conclude—12
recognize—11	estimate—10	prepare—11	experiment—9	devise—10	value—10
select—10	identify—10	show—11	discriminate—8	arrange—10	defend—10
record—10	generalize—10	compute—10	select—8	organize—10	estimate—10
match—9	interpret—10	relate—10	breakdown—8	collect—10	choose—9
relate—9	locate—10	construct—10	appraise—8	rearrange—9	critique—9
memorize—9	give—10	interpret—10	relate—8	prepare—9	argue—9
outline—6	distinguish—10	discover—9	test—8	reconstruct—9	measure—9
quote—6	extend—9	change—9	question—7	invent—9	recommend—9
enumerate—6	predict—9	produce—9	classify—7	generate—8	discriminate—8
write—6	recognize—9	manipulate—8	identify—7	modify—8	decide—7
tell—5	defend—8	schedule—8	outline—7	write—8	interpret—7
recite—4	classify—8	modify—8	illustrate—7	categorize—7	criticize—7
cite—4	infer—7	predict—8	point out—7	rewrite—7	contrast—6
duplicate—4	report—7	complete—6	subdivide—6	relate—7	rank—6
read—4	illustrate—7	choose—6	investigate—6	compile—7	predict—6
order—3	rewrite—6	classify—6	debate—6	revise—7	explain—6
tabulate—3	select—5	translate—5	criticize—6	reorganize—7	summarize—6
draw—3	contrast—5	determine—5	calculate—6	set up—6	score—5
review—3	differentiate—5	examine—5	inventory—6	summarize—5	grade—5
indicate—3	compare—5	calculate—5	prioritize—5	manage—5	revise—4
underline—3	indicate—3	investigate—4	correlate—5	generalize—5	relate—4
arrange—3	example—3	draw—4	explain—5	integrate—5	verify—4
know—2	observe—3	write—4	inspect—5	explain—5	test—4
point—2	elaborate—3	protect—3	detect—4	produce—5	validate—4
count—2	associate—3	derive—3	dissect—4	originate—4	attach—3
collect—2	visualize—2	chart—3	manage—3	tell—4	determine—3
meet—2	articulate—2	alphabetize—3	audit—3	incorporate—4	describe—3
study—2	clarify—2	simulate—3	characterize—3	facilitate—4	reframe—2
trace—2	subtract—2	process—3	order—3	hypothesize—4	convince—2
find—2	approximate—2	provide—3	deduce—3	substitute—3	prescribe—2
index—2	interpolate—2	capture 3	limit—3	specify—3	consider—2
locate—2	tell—2	project—3	connect—2	improve—3	release—2
show—1	detail—2	transcribe—3	diagnose—2	format—3	counsel—2
visualize—1	outline—2	organize—3	document—2	correspond—3	hire—2
examine—1	cite—2	shop—3	breadboard—2	model—3	prioritize—2
copy—1	picture graphically—2	establish—3	proofread—2	depict—3	deduce—1
sequence—1		attain—2	discover—2	synthesize—3	enforce—1
acquire—1	interact—2	graph—2	ensure—2	refer—3	advise—1

Table 9. (*Continued*)

Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
retell—1	conclude—2	assign—2	optimize—2	comply—3	motivate—1
view—1	characterize—2	allocate—2	maximize—2	enhance—2	core—1
observe—1	add—2	interconvert—2	confirm—2	import—2	uphold—1
tally—1	factor—2	experiment—2	divide—2	overhaul—2	resolve—1
imitate—1	compute—2	exercise—2	transform—2	animate—2	reconcile—1
follow—1	match—1	diminish—2	figure out—2	predict—2	discuss—1
	schedule—1	make—2	prepare—2	adapt—2	authenticate—1
	order—1	develop 2	file—2	cultivate—2	review—1
	sketch—1	ascertain—2	determine—2	code—2	monitor—1
	draw—1	tabulate—2	train—2	interface—2	weigh—1
	define—1	depreciate—2	size up—2	join—2	debate—1
	operate—1	subscribe—2	solve—2	handle—2	summary—1
	arrange—1	implement—2	lay out—2	anticipate—2	diagnose—1
	group—1	handle—2	survey—2	portray—2	infer—1
	extrapolate—1	transfer—2	group—2	express—2	mediate—1
	make sense of—1	factor—2	minimize—2	budget—2	prove—1
	examples—1	avoid—2	interrupt—2	cope—2	use—1
	diagram—1	expose—2	explore—2	debug—2	preserve—1
	interrelate—1	express—2	blueprint—2	perform—2	access—1
	represent—1	perform—2	arrange—2	communicate—2	consolidate—1
	trace—1	sequence—2	query—2	outline—2	
	shop—1	acquire—2	edit—1	prescribe—2	
	suggest—1	administer—2	prove—1	initiate—2	
	understand -1	personalize—2	isolate—1	network—2	
		adapt—2	reconcile—1	program—2	
		plot—2	troubleshoot—1	lecture—2	
		customize—2	sketch—1	dictate—2	
		interview—2	create—1	setup—1	
		paint—2	summarize—1	advise—1	
		explore—2	dramatize—1	document—1	
		utilize—2	employ—1	gather—1	
		report—2	inquire—1	derive—1	
		round off—2	link—1	abstract—1	
		figure—2	abstract—1	expand—1	
		price—2	establish—1	establish—1	
		carry out—1	organize—1	collaborate—1	
		coordinate—1	compute—1	conduct—1	
		simplify—1	devise—1	contribute—1	
		consult—1	setup—1	coordinate—1	
		maintain—1	moderate—1	compare—1	
		deliver—1	delegate—1	speculate—1	
		extend—1	research—1	simulate—1	
		imitate—1	model—1	progress—1	
		guide—1	practise—1	forecast—1	
		back up—1	operate—1	instruct—1	
		conduct—1	demonstrate—1	structure—1	
		multiply—1	schedule—1	intervene—1	
		build—1	check—1	frame—1	
		code—1	use—1	measure—1	
		contribute—1	chunk—1	estimate—1	
		obtain—1	choose—1	recommend—1	
		model—1	scrutinize—1	negotiate—1	
		compare—1	chart—1	consolidate—1	
		divide—1	apply—1	choose—1	
		follow up—1	allow—1	contrast—1	
		exhibit—1	extrapolate—1	reframe—1	
		tally—1	recognize—1	imagine—1	
		inform—1	show—1	individualize—1	
		diagram—1	modify—1	recognize—1	
		expand—1	administer—1	solve—1	
		amend—1	review—1	role-play—1	
		engineer—1	change—1	review—1	
		control—1	monitor—1	arbitrate—1	
		assess—1	direct—1	teach—1	
		concatenate—1	corroborate—1	supervise—1	
		execute—1	produce—1	assess—1	
		convey—1	negotiate—1	counsel—1	
		articulate—1	probe—1	exchange—1	
		restructure—1	accept—1	make up—1	
		criticize—1	design—1	brief—1	
		appraise—1	layout—1	reinforce—1	
		participate—1	interpret—1	unify—1	

Table 9. (*Continued*)

Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
		generalize—1	extract—1	pretend—1	
		instruct—1	manipulate—1	update—1	
		follow—1	category—1	validate—1	
		act—1	focus—1		
		screen—1	write—1		
		debate—1	predict—1		
		question—1	resolve—1		
		select—1			
		include—1			
		dissect—1			
		retrieve—1			
		inspect—1			
		prove—1			
		inventory—1			
		respond—1			
		comply—1			
		collect—1			

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