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Self-assessment of creative performance with a learning-by-doing approach: getting familiar with Novelty, Quality, Quantity and Variety

Niccolò Becattini[1], Tiziano Montecchi[2], Christopher Nikulin[2] and Gaetano Cascini[1]

[1]Politecnico di Milano, Milano, Italy
[2]Universidad Técnica Federico Santa María, Santiago/Valparaiso, Chile

Abstract: The paper discusses the outcomes of tailored ideation workshops (duration: 3 hours) for students of Design Engineering, not trained in design creativity dimensions and their assessment. 65 participants generated ideas to address a design problem, first individually and then in groups of 4/5 people. They were asked to cluster their ideas intuitively and then according to the structure of the genealogy tree. The reflections on the ideation experience (structured consistently with the Kolb cycle) helped them to easily consolidate their understanding of typical metrics of creativity (Novelty, Quality, Quantity and Variety). A survey questions them after four months from the workshop and the results show that the metrics are still clear, despite some controversial results appear for quantity. The investigation also shows that novelty has become the main driver to self-assess the effectiveness of their creative ideation performance.

Keywords: *Ideation, Innovation, Creativity Measurement, Experiential Learning, Genealogy tree*

1. Context, motivation and objective of the investigation

The academic curricula of Design Engineering students are typically populated by science and technology classes mixed with design studios activities where they can put into practice what they have learned to design solutions for (semi-)open problems. These kinds of design classes or studios typically follow a Project-Based Learning (PBL) pedagogy. Students have the chance to practice on the generation of ideas during one semester, to develop products and, more in general, solutions that are capable of addressing needs which are not necessarily explicit.

Nevertheless, despite the role of design engineers requires leveraging their creative skills and divergent thinking, academic curricula are not yet populated of classes that are tailored for the teaching of design creativity. The literature claims that there are significant efforts towards the integration of creativity training in classes (Starkey et al, 2016). Most of the efforts concern the teaching of design methods (e.g. Becattini and Cascini, 2016) or heuristics (e.g. Daly et al, 2012), with the purpose of directly improving divergent thinking and design space exploration. However, Charyton (2013) clearly stated that these teaching efforts to improve creativity or innovation capabilities are rarely expressed, investigated, or studied explicitly in coursework. Moreover, the progressive consolidation of these topics in academic curricula is currently just diluted in a few classes. Reviews of project assignments with experts are progressively becoming a common practice. Yet, this practice typically provides students with a critique on the quality of the proposed solutions i.e. on the targets the solutions is not addressing (Dannels et al, 2008). Indeed, less frequently these kinds of goal-oriented review sessions also provide structured feedback on the way students explored the design space and generated variants. This lack does not necessarily turn the feedback into a conscious change in the students' mindset towards a consolidated creative ideation behaviour. Several reviews are necessary before these concepts get perfused in students' mind and get properly assimilated. Nevertheless, these acquired skills remain probably tacit and hard to be formalized for fully conscious reuse. In fact, when students are asked about what creativity is, answers are typically naïve and based on the intuitive perception of what is creative and what has a high creative potential. This means that students, in most cases, have to learn how to be creative by themselves through the experience they earn by doing and practising the methods and the heuristics they try to apply.

In one of his lectures to the Institution of Civil Engineers, William Thomson stressed the importance of quantitative measurement to improve the knowledge about the qualities of what is studied in what has been summarised in the famous catchphrase, recently attributed to Deming or Drucker, "you cannot improve what you cannot measure" (Lord Kelvin, 1883). Stemming from this concept, the authors aim at introducing the concepts of creativity measurements into a design engineering academic curriculum that reflects the above-mentioned scenario. The expectation is that the introduction of the metrics proposed by Shah et al (2003) enables students to self-assess their creativity. On the one hand, novelty and quality/usefulness reflect the creativity of their ideas (Sarkar and Chakrabarti, 2010). On the other hand, quantity and the variety of their set of ideas positively correlate with divergent thinking and exploration of the design space.

Consistently with the constraints of an already consolidated and structured academic curriculum, the authors opted for the introduction of the creativity metrics in the curriculum by means of a workshop of short duration (3 hours). This choice allows the workshop to fit the current curriculum within the time constraints and make it accessible to students that are attending different years of teaching. The short duration, on the other hand, allows checking if and how much the workshop can become part of an existing teaching topic in the earliest years of the curriculum in next years and check its impact on already started cycles.

The next section motivates the choice of the pedagogical strategy adopted for the workshop as the most promising option to teach its topics in the existing academic curriculum. Section 3 describes the structure of the workshop and the questionnaire developed to check the effectiveness of teaching. Section 4 presents the outcomes of the data collection process carried out with the questionnaire which enables the authors to draw some conclusions that are discussed in the last section of the paper.

2. Pedagogical strategy for the workshop: experiential learning by Kolb's Cycle

The workshop had to be thought for students of Design Engineering attending a 5-year long curriculum organized into 10 semesters. These students, starting from the second year of their cycle, have to attend one design studio each semester. There, they are asked to conceptualize solutions starting from a design brief (year 2), engineering them (year 3) and made them ready to address the challenges of the market (year 4 and 5) and try to turn their solutions into innovations. In total, students are involved in these activities for one-fifth of their academic cycle (i.e. approximately one year). However, despite they receive lectures on design methods and tools as well as heuristics that typically foster creativity - e.g. classical TRIZ (Altshuller, 1984) and OTSM-TRIZ (Cavallucci and Khomenko, 2006) - they are not receiving any teaching that is specifically and explicitly focused on design creativity.

As mentioned in the introduction, the planning of a workshop for introducing students to the metrics of design creativity requires the choice of suitable pedagogical strategy to maximize the efficiency of teaching. The standard ex-cathedra lecture, despite being still the most diffused teaching strategy, appears to be not effective to allow students to familiarize and interiorize these concepts for their proficient reuse in their design practice. They can be exhausting for students and do not facilitate their active engagement (Groblinger et al, 2016).

Project-Based Learning (Thomas, 2000), as well as other innovative teaching approaches like the Flipped Classroom (Bishop and Verleger, 2013), appears to be too demanding for a short workshop to be run within a time frame of half-day of teaching activities. Despite they enable the active engagement

of the classroom, the former requires a definitely longer time frame to work on the project and provide the whole class with meaningful feedback; the latter needs the students to acquire some knowledge in advance, before the lecture, as the classroom becomes the moment for its consolidation. To the authors, this last approach appears to be more effective, as for PBL, on a longer time frame. In fact, the harmonization of knowledge within the classroom appears to be hardly achievable with a single event.
Kolb's cycle (Fig 1) is based on experiential learning (Kolb, 2014). Differently from standard ex-cathedra lectures, which are more, if not exclusively, based on reflective observation (Right – Fig 1) and abstract conceptualization (Down – Fig 1), this cycle facilitates the engagement by asking learners to actively experiment (Left – Fig 1) what otherwise remains abstract and run some experiences (Top – Fig 1) to improve learning. With the due differences, the Kolb's cycle enables students to learn by doing as PBL does. The experience to run, however, is less time-demanding than a whole project and, for this reason, the outcomes can be more easily communicated among peers. Therefore, all the students can participate in the abstract conceptualization stage, by sharing the reflections coming from concrete experiences with others, with mutual benefits.

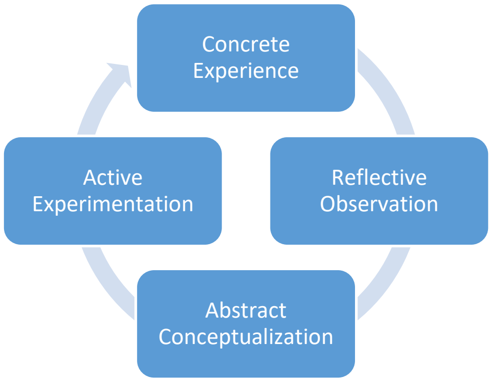

Figure 1. The main elements of experiential learning in Kolb's Cycle

According to the time constraints defined by the structure of the curricula, the workshop is therefore developed consistently with the pedagogical approach of the Kolb's cycle, that has already proved to be effective in contexts of engineering education (Abdulwahed and Nagy, 2009)

3. Design Creativity workshop structure and questionnaire for ex-post evaluation

3.1. Structure of the workshop

The workshop was organized as a 3h interactive session that follows the principles of experiential learning as for the Kolb's cycle. Sixty-five (65) students participated in two editions of the same. 23 of them at the Santiago Campus San Joaquín, 42 at the Campus Casa Central of Universidad Técnica Federico Santa María (USM) in Valparaíso (Chile). The participation in the workshop was left open to students attending year 2 to year 5 of the Design Engineering curriculum (Ingeniería en Diseño de Productos). As the university also runs activities with students after graduation, graduated students were also allowed to participate in the workshop. The ratio of these participants is approximately one-fourth of all the attendants.
Both the editions of the workshop were organized according to the following structure:

1. Differences between Creativity and Innovation (45 minutes)
    a. Intuitively formulated definitions noted on post-its each individual have to fill
    b. Collection of post-its and discussion on the outcomes driven by the educator/speaker
    c. Summary and identification of the main dimensions of both these concepts
2. Idea generation session (45 minutes)
    a. Presentation of the design task [Santiago: Recycling machine for Coffee Capsules; Valparaiso: Peanut sheller, as described in Becattini and Cascini (2019)].
    b. Generation of ideas – individually (15 minutes)

c. Reelaboration of ideas and generation of ideas – in groups composed of 3 or 4 attendees (25 minutes)

3. Group work: Analysis and classification of generated ideas (30 minutes)
    a. Classification of ideas and collection into thematic clusters defined by intuition (10 minutes)
    b. Brief introduction to genealogy tree (adapted from Shah et al, 2003) to classify solutions by purpose, functions to deliver, working principles and structural details (5 minutes)
    c. Re-classification of ideas according to the genealogy tree (15 minutes)
4. Open discussion on similarities and differences between the first and the second classification of ideas (45 minutes)
    a. Groups sharing info on the number of clusters of ideas they generated intuitively and according to the genealogy tree (20 minutes)
    b. Focus on the characteristics of the genealogy tree: number of levels, "branches and leaves" and differences between the ideas linked to the same cluster of ideas (25 minutes)
5. Wrap up by the educator/speaker (15 minutes)
    a. Summary of the main measures of creative ideation and their role in the evaluation of self and group idea generation activities (Novelty, Quality, Quantity, Variety).

Each workshop also included 10 minutes to warm-up the audience at the beginning and a 15-minute break between phase 2 and 3

With reference to the Kolb's cycle, during phase 1a the attendees were asked, based on their previous experience, to reflect on what they consider creative and innovative so that they can define it (reflective observation). Phases 1b and 1c, in turn, were moments of abstract conceptualization: the reflections they made individually, guided by the speaker, allowed them to distinguish between a creative outcome (characterized by novelty and usefulness) and an innovation (presented as an invention that is adopted by a reference market). According to the outcomes of phase 1, during phase 2 they were asked to generate creative ideas (active experimentation and concrete experience) to address a design task with novel and useful concepts. During phase 3 students were invited, again, to observe and reflect on what they did during the ideation session and find patterns within the set of ideas they produced (Figure 2 displays an example of the genealogy tree created during the workshop).

Figure 2. An example of a genealogy tree for the problem of the peanut sheller

Phase 4, again, allowed the students to collaboratively present to other groups what they have observed and collaboratively identify regularities in the way they collected and organized ideas. During this stage, the discussion was moderated by the educator/speaker to facilitate the harmonization of contents and allow similarities and differences to emerge. Genealogy trees enabled all the participants to focus on differences between ideas so that they can clearly spot those which are less common and more novel or original as well as more capable of addressing the requirements of the design task. On the other hand, the genealogy tree enabled groups to reflect on the number of ideas they generated, removing duplicates and finding differences at different levels of detail. These concepts were further stressed during the recap of phase 5 when these elements were explicitly referred to the four metrics of creative ideation.

3.2. Evaluating the learning outcomes with a questionnaire

The evaluation of the impact of the teaching activities required to reach as many students attending the workshop as possible and the data collection procedure to be effective. For this reason, a structured questionnaire appeared to be the most promising option. The following list summarizes the overall structure of the questionnaire, while its full version is available and accessible at the following URL: https://forms.gle/QjSCcUYD2L7qtc6r6

1. Demographical data collection (agreement/disagreement for personal data treatment, respondent's name and surname, age, sex, current occupation, location of the workshop);
2. Check for the level of attention during the workshop (3 multiple-choice questions (MCQ));
3. Check for the knowledge acquisition on the main characteristics of innovation, creative ideas and creative ideation (3 MCQs);
4. Check for the appropriate application of metrics for creative ideation effectiveness (4 MCQs, one per each of the metrics: Novelty, Quality, Quantity, Variety);
5. Check for the reflection ability/attitude with respect to idea generation (20 questions to express agreement/disagreement on a 0 to 10 Likert-scale, 5 questions per each of the metrics).

Beyond the first 3 multiple-choice questions (block 2), the questionnaire aims at checking if and how much the following Intended Learning Outcomes (ILOs), according to the Bloom's taxonomy (Krathwohl, 2002) have been achieved after the workshop:

- ILO 1: Know and understand the main dimensions that characterize an innovation, a creative idea and creative ideation effectiveness (questions of block 3);
- ILO 2: Analyse creative ideation outcomes and apply the metrics to distinguish more and less creative ideation effectiveness (block 4);
- ILO 3: Apply the metrics as a reference target to self-evaluate own ideation performance (block 5).

The learning outcomes, in principle, should be more effective if they demonstrate to be persistent on a medium or long term perspective. Therefore, the students filled in the questionnaire four months after the workshop. A control group of students that did not attend the workshops were also asked to fill in the questionnaire to run comparisons with the attendees.

4. Analysis and discussion of the results

The following subsections compare the results after the completion of the questionnaire by the undergraduate students that attended the workshop and a cohort of undergraduate students not attending the workshop, here considered as the control group. The answers collected with the questionnaire are not capable of covering the whole set of participants, as students were not obliged to fill in the questionnaire and they can opt-out of the data collection procedure if they do not want to share their data. This option, despite limiting the data collection procedure, was necessary to properly manage students' data coherently with the standards of ethics (e.g. the collected answers could be potentially used also to inform the evaluation and the grade assignment process for the classes of their study plan). In the following, a set of 14 answers from undergraduate students attending the workshop and 7 answers from the control group (students enrolled in the Design Engineering curriculum at USM) are compared.

4.1. Know and understand the main dimensions that characterize an innovation, a creative idea and idea generation processes

Table 1 collects the results for the first question "Choose the TWO characteristics which are crucial for innovation. A solution, to be considered an innovation, must be...". Students have to select the options "Inventive" and "Adopted by the market" among a set of 8 alternatives (chi-square p-value 0,186).

Table 1. Results for the question on innovation characteristics

Attendees (Undergraduate)	Control Group (Undergraduate)	
92,9%	71,4%	**One or more correct answers**
7,1%	28.6%	**No correct answers**

Table 2. Results for the question on the characteristics of a creative idea

Attendees (Undergraduate)	Control Group (Undergraduate)	
28,6%	57,1%	**Just one answer**
71,4%	42,9%	**Both answers correct**

Table 3. Results for the question on the characteristics of creative ideation effectiveness

Attendees (Undergraduate)	Control Group (Undergraduate)	
7,1%	14,3%	**Just one correct answer**
14,3%	71,4%	**Just 2 correct answers**
42,9%	14,3%	**Just 3 correct answers**
35,7%	0%	**All the correct options selected**

More precisely, almost 80% of the attendees recognize "inventive" as the right answer (43% Control group) while more than 55% of both cohorts chose market adoption.
Table 2 shows the results for the question "Choose TWO characteristics that are required for an idea to be considered creative" in a set of 8 possible alternatives (correct options: Novel or Original and Useful, chi-square p-value 0,204). The results show that none of the respondents in both the samples provided wrong answers. It is also worth noticing that just the 14% of the respondents in the control group (except those who chose both the correct options) identified novelty or originality as one of the crucial dimensions of a creative idea.
Table 3 presents the results for the question "Choose, among the following options, the FOUR characteristics that, during the workshop, have been mentioned as crucial to measure creative ideation effectiveness" (correct options: Novelty, Quality, Quantity, Variety, to be selected in a set of 10 alternatives, chi-square p-value 0,037). As for the previous question, nobody in the two samples provided fully wrong answers, nevertheless it is worth noticing how the results from the control group are distributed similarly to the expectations of a random selection of answers, which confirms the statistical validity of the results of the test group and a satisfactory achievement for ILO 1.

4.2. Analyse creative ideation outcomes and apply the metrics to distinguish more and less creative idea generation processes

For this ILO (#2), respondents have to answers questions related to ideas or set of ideas addressing a simple design problem: lift (move upwards) a weight of 1 kg. On Novelty, respondents have to select the 2-3 most original solutions in a set of 16 alternative working principles (correct answers are the options out of the attendants' background knowledge, i.e. mechanics and thermodynamics). The questions on Variety and Quantity had just one correct answer each in a set of 4 possible answers. Correct answers respectively mention a wider set of working principles leveraging fields of interactions in different domains, (mechanics, electromagnetism, chemistry, biology) and a higher number of ideas, compared to the other options. For what concerns Quality, 5 alternatives were available and the problem had additional requirements, to make students choose the option that better addresses all of them among the proposed solutions (which spots the correct answer). Table 4 presents results on Novelty (MCQ, multiple correct answers), Table 5 on the remaining three metrics (MCQ, one correct answer).

Table 4. Results for the question on the selection of the most novel ideas in a set of 16 alternatives

Attendees (Undergraduate)	Control Group (Undergraduate)	
35,7%	57,1%	**No correct choice**
64,3%	42,9%	**One or more correct answers**

Table 5. Results for the questions on the quality of ideas, the quantity and the variety in set of ideas

Attendees (Undergraduate)			Control Group (Undergraduate)			
Quality	**Quantity**	**Variety**	**Quality**	**Quantity**	**Variety**	
78,6%	21,4%	71,4%	28,6%	42,9%	28,6%	**Correct answer**
21,4%	78,6%	28,6%	71,4%	57,1%	71,4%	**Wrong answer**

The results for Novelty (chi-square p-value 0,350) show a general trend towards slightly better results from the test group. As the question explicitly mentioned the comparison with the "state of the art" solutions, the answers are by nature subject to a certain unpredictable variability. However, the 16 options for this question describe ideas leveraging working principles that are mostly mechanical or thermal, according to the expectation that design engineering students have a stronger background in mechanics and thermodynamics. For this reason, solutions leveraging chemistry and biology were expected to be considered "correct" compared to others. The results for Quality and Variety (respectively chi-square p-value 0,102 and 0,061), confirm the higher rate of correct answers by attendees than the ones by the control group. The results for Quantity show that the Control Group performed better than the attendees (chi-square p-value 0,306). What is most surprising is the majority of wrong answers in both the samples for this metrics, which should be the simplest to recognize.

4.3. Apply the metrics as a reference target to self-evaluate own ideation performance

This set of 20 questions required the respondents to express their agreement or disagreement to assertive statements formulated in a polarized way (e.g.: I ALWAYS/NEVER have the behaviour/attitude X when generating ideas). Per each of the four metrics of creative ideation effectiveness, 5 statements required the respondents to assign a value corresponding to their viewpoint (0 = strongly disagree; 10 = strongly agree). To check for the coherence of answers within the same set/metrics, each subset of 5 questions has statements to be positively (high values) or negatively correlated (low values) to the creative behaviour/attitude (i.e. statements respectively corresponding to a creative and non-creative attitude). The comparison between attendees and the control group was carried out with a two-tailed heteroskedastic t-test on the mean values. A positive difference between attendees and the control group are expected for answers to be positively correlated with a creative attitude. Negative differences are expected for answers to be negatively correlated with a creative attitude.

The collected answers on Novelty are the only ones whose results are harmonized over the 5 statements, showing values globally reflecting the expectations. The mean difference (absolute value) is 2,414 (st. dev 0,733), where the smallest difference is 1,643 and the biggest is 3,429. Despite not all these five differences have a strong statistical significance, p-values are generally small or very small (max p-value 0,123; min p-value 0,002; mean p-value 0,059), which should be considered in any case as promising results considering the small number of respondents.

On the other hand, the answers concerning the impact of the workshop on changing the attitude about Quality, Quantity and Variety resulted in small differences between the two groups, which make their statistical significance poorly meaningful. Moreover, for one-third of the 15 remaining questions (1 for quality, 2 each for variety and quantity) the control group provided answers showing a more creative attitude than the attendees (33%), while the test group had a more creative attitude in the remaining two-thirds of cases (66%), showing a just partial achievement of ILO 3.

5. Conclusions and implications

The paper presents the planning and the development of an educational 3-hour workshop to introduce metrics for design creativity (novelty, quality, quantity and variety of ideas) in a design engineering curriculum where these topics are not explicitly taught. The purpose of this educational intervention is based on the assumption that the knowledge and understanding of the characteristics of innovation, creative ideas and creative ideation processes can be beneficial to Design Engineering students (Intended Learning Outcome 1). This is expected to be a requirement for the analysis of own generated set of ideas and for the application of creative ideation metrics on them, in order to have a positive impact on their overall creative ideation behaviour (Intended Learning Outcome 2 and 3). The workshop has been carried out two times at USM, in Santiago and Valparaíso (Chile) with 65 students. The Intended Learning Outcomes have been verified after four months from the workshop dates by means of a tailored questionnaire composed of 30 questions (10 multiple-choice – 20 agreement questions on a Likert scale). The answers provided by the attendees allowed the comparison with the ones provided by students of the same academic curriculum that did not attend the workshop. The small number of collected answers (attendees -14 - and other students -7- were not forced to answer the questionnaire) show generally positive results for the ILO 1 about knowledge acquisition and understanding. The attendees have properly acquired the knowledge of what characterize invention, creative ideas and creative ideation processes, despite these results have statistical significance just for creative ideation effectiveness. For what concerns the application of the metrics of novelty, quality and variety (ILO 2) the attendees showed better results than the control group, while for the quantity of ideas the control group intuitively applied the metrics better than the attendees. The overall attitude of attendees (ILO 3) have changed positively for what concerns novelty, not for the other 3 metrics that are still showing some controversial results. These results, despite promising also with a small number of respondents for the validation, also show that new workshops of this kind require some adaptation, whose impact has to be checked on a longitudinal perspective across the academic curriculum for a complete evaluation of the generated benefits.

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