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Zero Gravity : radical creativity by multidisciplinary collaboration

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Abstract

In June 2013, the report "ARTS+ENG, Future Collaborative Academic Models at Aalto: Cooperation between the Schools of Arts, Design and Architecture, and the School of Engineering in Aalto University," was published. The most significant collaboration endeavor between the schools was the project work course, here referred to as The Synthesis Studio, a platform for multidisciplinary collaboration, which first has been established as ARTS-ENG Project Course in 2016. Since then the course underwent a transformation from disciplinary oriented, thematic baskets to the "discipline-free" topics of "Zero Gravity", always in mind that its pedagogic intent is to lay an early foundation for the formation of trans- and multidisciplinary skills in future levels of study and to trigger radical creativity. This paper looks into the ideas of radical creativity and presents the backgrounds and the constant development of the project course as a major experiment at Aalto University, including its challenging pedagogical and logistic tasks, but offering unparalleled opportunities to create multiple cross connections in the beginning of the undergraduate studies. In 2019, the course was accompanied by creativity tests, an Alternate Uses Test (AUT) and a ShapeStorm (SS) Exercise, investigating the course´s impact and its significantly positive effect on students' creativity.

Keywords: radical creativity, multidisciplinary teaching, creativity test, structures and architecture.

1. Creativity, Radical Thinking and Radical Creativity

Creativity thinking isn't limited to artistic types of persons and it isn´t limited to artistic disciplines, as it is a skill that anyone can nurture and develop (Doyle [6]). Creative thinking can be associated with outside the box thinking. Often, creativity involves lateral thinking, which is the ability to perceive patterns that are not obvious (Lewis [16]). Creative thinking might mean devising new ways to carry out tasks, solve problems, and meet challenges. It means bringing a fresh, and sometimes unorthodox, perspective to your questions, work and consequently solutions. This way of thinking can help departments and organizations be more productive (Landry [14]). So, creativity is the essential driving force, and creative thinkers are the drivers entrusted to propel the technology-driven industry to the pinnacle of innovations in all engineering sectors including architecture and engineering but also arts and design (Deo, et al. [5]). As creativity seems key to developing novel and useful ideas about products, services, and procedures in organizations (Shalley and Gilson [22]) it is increasingly becoming important in organizations. The reasons can be identified as advantages in organizational development, performance, and competitiveness (Anderson, et al. [1]), and given its importance creativity increasingly

is subject of research (Hirst, et al. [9]). (Zhang, et al. [27]) found that the more employees perceived their organization climate to be creative and indicated they had a creative role identity, the stronger their creative behavior. Furthermore, creative team mindset was related to creative behavior (divergent thinking). Their final model indicated that creative team mindset was related to creative behavior through its relationship with creative role identity. It appears that creativity in groups is also an important factor that can increase understanding of creativity and foster such creativity. With respect to diversity (van Knippenberg, et al. [25]), which can be also reinterpreted as multidisciplinarity, organizational or team mindset has been found of importance. Creative innovations are the backbone of the modern industry from both perspectives, the product-design, and the user-oriented engineering. According to Sternberg's theory of creativity essential parameters or enablers of creativity include intelligence, environment, knowledge, motivation, personality and thinking (Sternberg, et al. [24]). However, Design and Engineering have foundationally different values, which are reflected in how the respective education as well as the professional practices are organized (Ylirisku and Filz [26]). Adherence to these values introduces problems for the planning of studies where different pedagogical approaches confront, whilst both design and engineering tasks are explored, and projects conducted. It is challenging to develop adaptable didactics that serve both viewpoints and perspectives.

For engineers to be creative is different than for designers or artists. Engineering creativity is expected to demonstrate functionality, engineers are the creators of technology, and technology is the reflection of their creativity. So, basic skills are usually required before engineers can create things that work reliably. These skills include analysis, mathematics, physics, programming, and logic. But the engineers´ desire for well-defined parameters and problem statements for the sake of predictable and calculable health and economic risks conflict with real design problems, which mostly are "notoriously ill-behaved and cannot be formulated exhaustively and definitely" (Rittel, et al. [18]). So, it would be difficult to train particular analytical or logical skills in such an uncertain context.

Design is mostly based and thought through iterative and constructive exploration. Through feedback from and weighting of various sources a parametric thinking model is set up. This process even includes the design question itself and the relevance of possible results are usually justified and argued by references. It is significant part of creative design process to break existing structures to discover and to create something innovative. In this context, vagueness, uncertainty and thinking in gradients are considered as a source of the new rather than as a limitation. Design involves this approach as a logical process of not thinking linearly on well-established paths, but rather developing "lateral" solutions and "lateral" ways of thinking (De Bono [3]). This means that reasoning is based on the not immediately obvious or obtainable through hierarchical logic (De Bono [4]). This triggers a "jump" to new perspectives and thoughts, often reflectively considering our understanding of ideas (De Bono [3]). Design and its creative thinking, "it´s a dynamic process that often involves making new connections, crossing disciplines, and using metaphors and analogies (Robinson [19]). The essence of creativity, then, is the ability to take risks and being comfortable with it: radical creativity.

Radical thinking and radical creativity are about empowering people with a basic, natural skepticisms by never assuming that issues are fully proven, or absolutely true, or too sacred for another reinvestigation. This approach inspires the creative thinking process by allowing to question the world around including the predominant social and political discourses found in society. At universities, this thinking has been adopted by engineering disciplines in the last years. Parametric engineering tools such as parametric 3d engineering software, modelers, physics engines and genetic-algorithm-based solvers have been introduced and made accessible for designers and engineers. Engineering schools like design schools have begun to argue for what they call "design thinking", and to rediscover and to promote multidisciplinarity as a parallel track to expert knowledge. (Ross and Vinson [20]) highlighted that nothing in schooling is "neutral", but it is a decidedly political act. Consequently, students need to be aware of the political nature of teaching to develop the autonomy to make their own decisions and to be engaged in their own learning.

2. ARTS+ENG, Future Collaborative Academic Models

In June 2013, the report "ARTS+ENG, Future Collaborative Academic Models at Aalto: Cooperation between the Schools of Arts, Design and Architecture, and the School of Engineering in Aalto University," was published (Hollmén and Rose [10]). In his foreword, Juha Paavola, former Vice Dean of Aalto School of Engineering explains the moving of the Department of Architecture out of the School of Engineering at Aalto University as a starting point for a remarkable development process of the educational collaboration between these University units. On one hand the need for this was significant because the education of architects and civil engineers had diverged far away from each other, since for example the students in both disciplines have been different because they have also been chosen by applying completely different criteria. On the other hand, this has turned in practice the roles of each profession to be separated as well, though the cooperation between them in all projects is absolutely necessary.

The report identifies specialized expertise that has become the prevailing denominator of Western culture as a major pedagogic challenge. The progressive deepening of each discipline over time has taken all of them to a level that is out of reach of all-round education and common knowledge. Subsequently, the disciplines tend to segregate, as the expertise grows deeper. Hollmén and Rose [10] explain, that "the 'big picture' to which all specialisms somehow connect becomes a significant challenge both within and across disciplines, and as it relates also to the public sphere. Knowledge relationships may become distorted from an individual perspective. Insights emerging from other domains cannot be accessed by the individual other than via intuitive means, additional study, or via commercially mediated information. These factors establish the need for a bridging strategy with multiple threads, visual, technical, mathematical, experiential, experimental, and applied" (Hollmén and Rose [10]). The authors identify a pressing need for techniques of appropriate collaboration to augment existing strengths, as engineering is often considered as a discipline that includes little creativity. Entrance examinations of the universities mostly underline the presumption of being either creative-artistic or scientifically orientated. Hollmén and Rose [10] conclude that this presumed dichotomy is fundamentally false, and that the societal and cultural challenges tend to have greater complexity than can be addressed by single disciplines. As bridging elements new pedagogic entities and a stepwise curriculum implementation is suggested. The deepening of cooperation between architecture, design and engineering aspires and to enhance a broad and interdisciplinary way of thinking. New innovations and social impact and consciousness being the objectives, the key factor is to improve mutual interaction between students from various disciplines. Therefore, the report defines the general cooperation objectives as follows:

- Diffuse the mental barriers between the various disciplines
- Create friendship between students from different fields of study
- Enhance understanding of one's own contextual expertise
- Enable development of diversified work in pairs and groups
- Engender artistic group intelligence and social consciousness

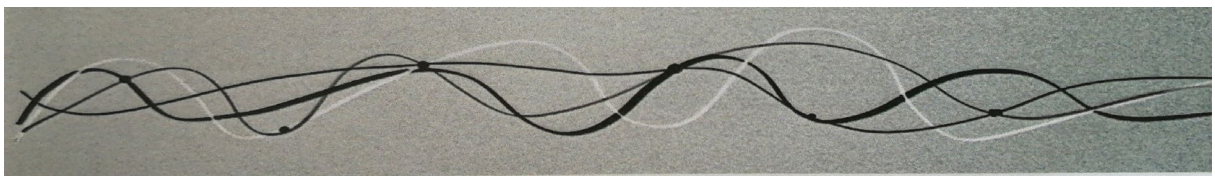


Figure 1: Cooperation Objectives [drawing by Chris Rose]

References and Impressions from the Rhode Island School of Design (RISD), the University of Bath and Stanford University have been collected and compared to existing and on-going ARTS + ENG collaborative models at Aalto like the Wood Program, Urban Planning, and the FEN Network.

3. The Synthesis Studio: a platform for multidisciplinary collaboration

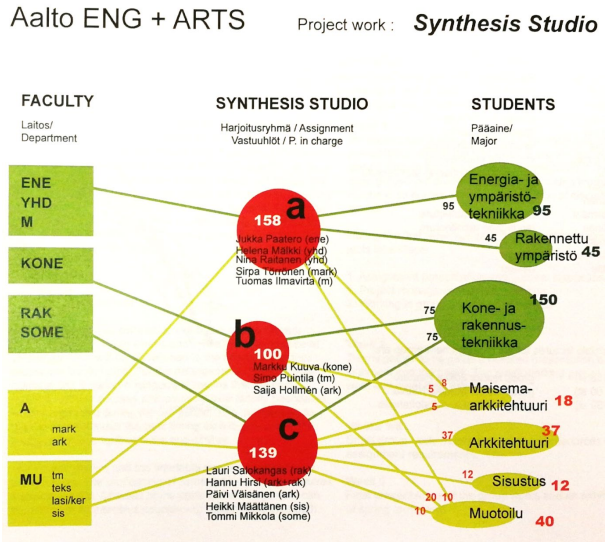
The most significant collaboration endeavor between the Schools of Arts, Design and Architecture, and the School of Engineering on the bachelor level studies was the project work course, here referred to as The Synthesis Studio (Figure 2). The Synthesis Studio is defined as a course in the early stage of the studies, concentrating in communication, teamwork, and a sense of community, as well as general academic study skills and academic identity building. It is concerned with the development of creative and applied skills of synthesis in design thinking, where knowledge stemming from different disciplines is necessary for the student both individually and in groups to experience what synthesis means. The course offers a platform for diversified cross-disciplinary teaching and learning, as part of the cooperation between the ARTS+ENG. The focus of the studio is, on the other hand, on the learning processes and group dynamics, but equally on the assignments that the students work on, build knowledge together, and learn to share their own insights in a multidisciplinary teamwork context. It is not about 'mixing' of disciplines. The pedagogic intent is to lay an early foundation for the formation of trans-disciplinary skills in future levels of study. The Synthesis Studio is an opportunity to explore various methods for teaching and learning. One possible direction of assignments is to engage the students in a specific problem that produces an embodied cognition through learning by doing, for example by experimenting gravity, force and counterforce. By building a tangible product together, the students' aware-ness of the world is enriched through personal and reciprocal immersion to a specific problem. The meaningfulness of the studies increases, as the significance of mathematics and natural sciences gets new dimensions, and as the course emphasizes the student's own role as an active learner. It is seen as an essential goal to have the support of the group, competent tutoring, learning by doing, experiencing with all the senses, and gaining the feeling of community, while processing knowledge building as a social endeavor. So, the aims of the Synthesis Studio and the associated outcomes for the learners have been defined as follows:

- Learning by doing
- Active role of the student
- Focus on the learning process
- Evolving work skills in groups
- Independent responsibility for a part of the assignment
- Positive dependence between group members
- Shared knowledge building
- Shared responsibility for learning
- Contact with students from other fields
- Permission to be wrong
- Joy and enthusiasm!

In the undergraduate curriculum of the Aalto ENG (Department of Civil Engineering and Department of Mechanical Engineering) and Aalto ARTS (Department of Architecture and Department of Design), it was a compulsory and integral part of the studies for the 1st year students from the spring of 2016 on. The annual intake of Aalto ENG to the undergraduate programs has been about 290 students, along with about 55 students from the Department of Architecture and about 52 students from the Department of Design. Altogether about 400 first year students were supposed to participate. The course was planned as an interactive teaching platform, where topical themes were processed within multidisciplinary working groups. As a major experiment within Aalto University, the coordinating of almost 400 students across departments and university boarders is a challenging pedagogical and logistic task, but with a remarkable opening, offering unparalleled opportunities to create multiple connections in the beginning of the undergraduate studies.

Universities can provide an ecosystem inclusive of all essential parameters described by Sternberg (Sternberg, et al. and play an increasingly important role in boosting students' creativity. Simultaneously, the academic environment can provide students a safe sandbox for testing new approaches without economic threats. Multidisciplinary courses with a project-based learning approach might be a way forward. However, there are many practical challenges and limitations, such as students' ability to work in a team, appropriate integration of multidisciplinarity, and pedagogical competencies of the teacher that needs to be tackled before expecting creativity and innovative results from students (Perrenet, et al. [17]).

In the first implementation of the Synthesis Studio the concept of cross connections of various teaching contents and the teachers´ specialist knowledge for a multidisciplinary teamwork setting was directly translated into a project course. Due to the massive number of participating students mainly from Mechanical Engineering, Structural and Civil Engineering, Architecture and Industrial Design, thematic baskets (a, b, c) with topics in close relation to real-world projects have been set up. The disciplinary oriented baskets attracted disciplinary oriented groups of students, and the cross connections between students, teachers and disciplines were often reduced to organizing timetables and flowcharts. Finally, this setting again caused a separation of disciplines, while group members from other disciplines frequently felt superfluous and unable to contribute to the project work.



ENE = Energiatekniikan laitos, Department of Energy Technology

YHD = Yhdyskunta-ja ymparistotekniikan laitos, Department of Civil and Environmental Engineering
KONE = Koneenrakennustekniikan laitos, Department of Engineering Design and Production

RAK = Rakennustekniikan laitos, Department of Civil and Structural Engineering

SOME = Sovelletun mekaniikan laitos, Department of Applied Mechanics

M = Maankayttotieteiden laitos, Department of Real Estate, Planning and Geoinformatics

A= Arkkitehtuurin laitos, Department of Architecture (mark = landscape arch. / ark = architecture)

MU = Muotoilun laitos, Department of Design (tm = industrial design / teks = textiles / lasi/ker = glass and ceramics / sis = interior design)

Figure 2: The cross connections of various teaching contents and the teachers´ specialist knowledge for a multidisciplinary teamwork setting (Hollmén and Rose [10])

4. The ARTS-ENG Project Course 2018

By 2017, the collaboration between the Schools of ARTS and ENG has been further developed and deepened by two newly appointed professors, the Professor of Design of Structures and the Professor of Structures and Architecture. Both positions are shared in research and teaching between the Department of Architecture in Aalto ARTS and Department of Civil and Structural Engineering in Aalto ENG. In 2017, the Professor of Structures and Architecture has been asked to fundamentally rethink the ARTS-ENG Project Course for the year 2018 (Filz, Guenther [7]). The major changes can be summed up as follows:

Firstly, a common topic has been selected for all students and teachers, which is chosen in a way that it cannot explicitly be assigned to one of the involved disciplines. This way the students should see themselves more as contributors to the common goal instead of representatives of their discipline “simulating” traditional and stereotypical roles. Secondly, all efforts support the success of the project. Therefore, no distracting subtasks or assignments were asked from the students. Thirdly, all (18) involved teachers contributed with their input lectures to the common topic. Fourthly, the student teams were supposed to act highly self-responsible, especially when booking consulting hours with the teachers. And fifthly, most of the student`s workload was dedicated to team-activities – from lectures, workshops to face-to-face teaching. The booking system for the consulting hours guaranteed a rotational system, which means that the student-teams would be in contact with several teachers, with diverse methods and various advices.

In 2018, the "Zero Gravity Experience" is set up as reflexive studio practice that entails an iterative cycle of research-action-reflection. In more detail, it is an introduction into design-thinking by means of multidisciplinary approach. The course aims for an understanding of "project" as modulator of diverse information in the early stage of the studies, concentrating in communication, teamwork, and a sense of community, as well as general academic study skills and academic identity building. It is concerned with the development of creative and applied skills of synthesis in design thinking, where knowledge stemming from different disciplines is necessary for the student both individually and in groups to experience what synthesis means. The course title "Zero Gravity Experience" was chosen to convey a wide variety of aspects of the course to students, including the philosophy that visions, ideas, and thoughts have zero gravity – everything is possible. "Zero Gravity" asked for a "discipline-free" topic that would allow all students to enter and contribute to its development with equal ease. Simultaneously qualities of lightness, adaptivity and ephemerality and sustainability are emphasized to encourage students to also think of design for disassembly, geometry, material properties, kinematics, architectural creation, and industrial design. As mentioned above, it is not about "mixing" of disciplines, but rather discovering one`s own potential to integrate into a larger team and to proactively contribute to the team`s project. This way students would discover experience as increase of knowledge and experience as sensation.

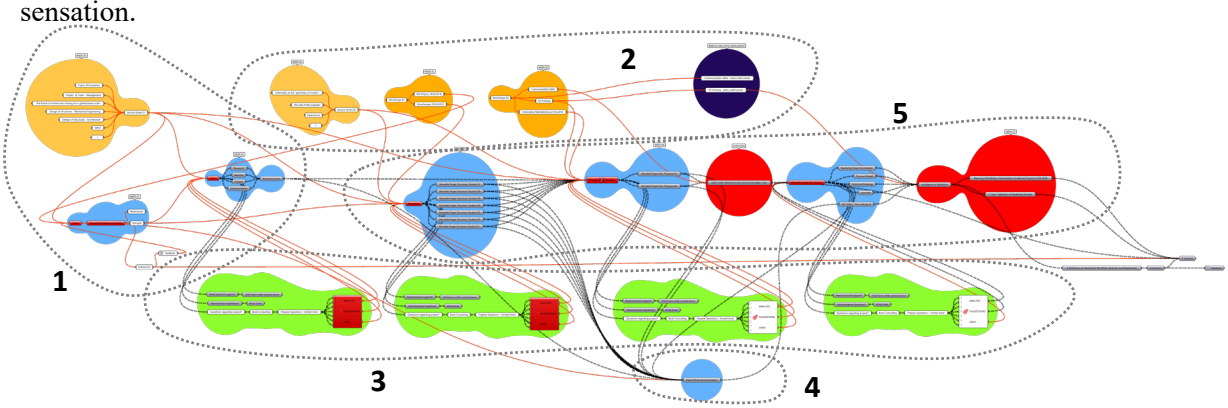


Figure 3: Visualized system of cross connections and loops guiding students through the ARTS-ENG Project Course 2018 [by G. H. Filz]

As shown in figure 3, the course was visualized as system of cross connections and loops guiding students through the ARTS-ENG Project Course 2018. Starting point of 2018´s exploration has been on one hand "kites" as light, joyful structures with clear structural and material concepts, and on the other hand "movability" as dynamic, non-stationary, ever changing constructs of temporary or even ephemeral character. The first phase of exploration was accompanied by a series of intense 30- to 60-minute input-lectures from different disciplines (Figure 3-1). These lectures shall be understood as teasers rather than as recipes or manuals. An initial SWOT analysis (Figure 3-1) helped the student teams to understand their own and the team´s skills and capacities, and workshops (Figure 3-2) have provided the opportunity to improve needed skills in software, 3d-printing, project management, hands-on techniques as well as in communication. In a second phase the two given but open topics were merged into new and unique projects by each team (Figure 3-5). The whole process was documented by means of sketches, analyses, drawings, texts, photos, physical and digital models, and short videos (Figure 3-4). In contrast to mandatory attendance at lectures and workshops the project teams self-responsibly booked consulting hours from the experts, whenever feedback, advice or help was needed (Figure 3-3). The looping (research-action-reflection) and simultaneously distilling processes in reflective studio practice were highly effective for the student´s progress. Simultaneously this approach asked for well-organized teamwork, communication, and coordination to achieve highly sophisticated projects and appealing designs. The 7-weeks course included a mid-term review with invited crits and without grading, and a final exhibition provided a platform for presentation, discussion and comparing results

(Figure 3-5). Even though the results (Figure 4) from the course and the created projects were clearly above average, and the teachers were very satisfied with the comparably steep learning curve, students were unsatisfied with some aspects. Some students would have preferred to invest time into the project instead of attending expert lectures from their own discipline. The freedom in picking workshops, in self-responsibly booking consulting hours, but mainly the fact of not working towards a clearly predefined goal seemed to be the most confusing factors for many students. Obviously, the provided freedom had led to uncertainty among many participants, and, subsequently, resistance in some cases.

Figure 4: “Zero Gravity” submissions 2018; 5 from 40 modified kites and mechanisms

5. The ARTS-ENG Project Course 2019

Based on the experience of the previous ARTS-ENG project course and related student feedback, the course setting was modified while maintaining its basic principle. To find out whether the assessment of the teachers involved was biased, the course was observed by invited external experts. The creativity tests at the beginning and after the 7-week course were to provide objective information about the impact of the new course on the creativity of the students, which had already been perceived by the teachers as an increase in quality the year before. Students were not informed that the creativity tests were directly related to the course and their projects.

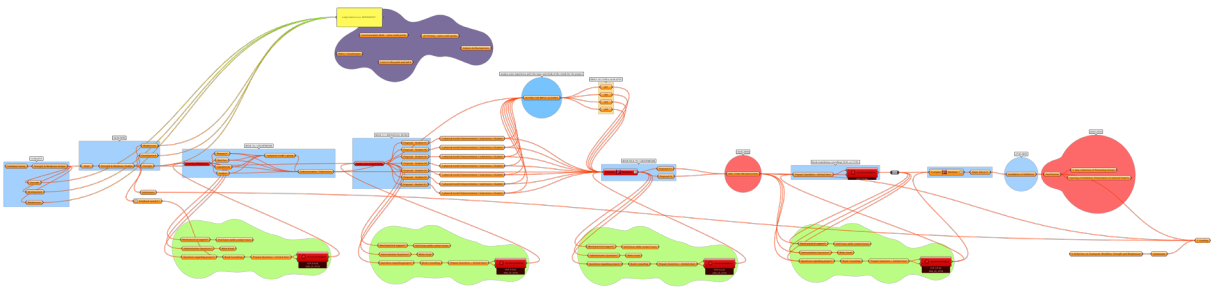


Figure 5: Visualized system of cross connections and loops guiding students, who have chosen option 1 “explore by experimenting” through the ARTS-ENG Project Course 2019 [by G. H. Filz]

5.1. Modifications and Option

In 2019, the ARTS-ENG Project Course "Zero Gravity" the on-campus spaces at Sähkömiehentie were exclusively reserved for the student teams to meet, discuss, and work. The inspiring spaces provide unique spatial qualities with large skylights, gallery views and an industrial flair, and were used for consulting meetings too.

The students were offered 2 options to successfully complete the project course, namely the option 1 to explore by experimenting and the option 2 to explore by full scale, hands-on experience. Thus, both options would address the same topic – modified Steward Gough Platforms and their actuation (Filz, et al. [8]), but would be different in terms of time and method of knowledge transfer. While in option 2 the knowledge of theory and implementation was imparted to the students in parallel with the guided implementation, in option 1 they independently explored the principles of kinematics, actuation and structure by means of small tasks. For option 1 multidisciplinary teams of 7 students each were asked to explore the principles of a kinematic structure and creative options for its actuation. Merging the findings with a possible "function" the final project output would emerge a catalogue of possibilities. Absolutely free in scale, the projects´ lightness and motion in space will "overcome" gravity. Opting for exploration by full scale, hands-on experience, a team of 15 students (all disciplines represented) will be advised in the principles of kinematics, structures and geometry with the aim to realize an experimental, kinematic lightweight structure in full scale. However, this group of students interested in learning by doing, and in directly linking recent research to reality, would accept a higher workload.

The above-mentioned modifications mainly concerned option 1 "explore by experimenting", and can be summarized as follows: After the initial individual and teams´ SWOT analyses the student teams immediately started to explore the principles of a kinematic Steward-Gough platform as a group and creative options for its actuation as individuals. Voluntary participation at workshops would complement students´ skills in software, 3d-printing, project management, hands-on techniques as well as in communication. Like in the previous year, the project teams self-responsibly booked consulting hours from the experts, whenever feedback, advice or help was needed. After 3 from 7 weeks, when students knew more about the challenging aspects of their projects a pool of about 8 input lectures was offered. The teams were asked to give their vote for 4 from 8 lectures that would best support the progress of their projects. After the mid-term review a mandatory consulting meeting with experts was scheduled with each student team to discuss the feedback from the crits. The last 3 weeks of the project course were used to have additional consulting, and to prepare the projects for the final exhibition and presentation.

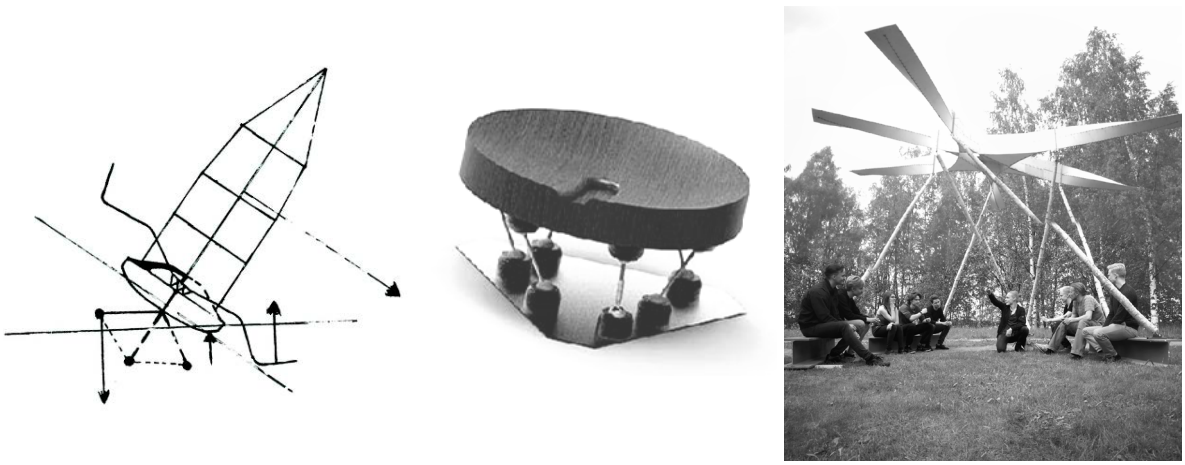


Figure 6: "Zero Gravity 2019" output - from functional sailing design proposals (1), to artistic applications (Raincatcher) (2), to full scale, kinematic prototype "Zero Gravity 1.0" (3)

Overall, the created projects (Figure 6 -1&2) were of good quality and students were more satisfied with the mix of guidance and freedom in teaching and learning. However, the teams that extensively used the reserved on-campus spaces achieved comparably more creative, more detailed, and more mature projects. We assume that, being part of the studio atmosphere at the on-campus spaces, the increased exchange with other teams and the coincidental meeting with teachers may be decisive for this.

The full scale, hands-on team realized the importance of each individual of the team after a quite chaotic, 2-week period, a phase of transforming the team with passively waiting for instructions behavior into actively communicating task forces. By raising questions, making suggestions, and trying to implement their own ideas, the students made the project their project, and finally realized "Zero Greavity 1.0" as shown in figure 6-3. We observed significantly increased motivation amongst students, a loss of disciplinary thinking, and a focused way of contributing with individual skills and knowledge to the benefit of the project. In addition, the students seemed to become increasingly self-confident in thinking out loud, in taking decisions and in teaching each other.

5.2. Creativity Assessment

There are multiple ways to assess creativity. Literature proposes the usage of engineering design tasks or standardized tests to assess creativity (Chen, et al. [2]), (Kershaw, et al. [12]), (LeGendre, et al. [15]). Creativity assessment consists of measuring several aspects such as Novelty, Originality, Fluency or Quantity, and Feasibility, and researchers have developed different metrics to assess these (Shah, et al. [21]), (Kershaw, et al. [11]), (Sosa, et al. [23]). For this creativity assessment all participants were from the ARTS-ENG Project course 2019 at Aalto University, Finland. It is a bachelor level course, and at that time a mandatory in the School of Engineering and an elective course in the School of Arts, Design, and Architecture. We aimed to investigate the impact of this course on students' creativity with the goal to see if the short-term intervention of a 7-week course would show a positive effect. The intention and general purpose of the study was conveyed without revealing experimental details to the participants. The participants were informed that their participation at this independent study was voluntary and would not affect grades earned in the ARTS-ENG course. Out of 244 students, 146 voluntarily participated in this study. In the context of this paper we provide a summary of the test setting, methods used, data coding, evaluation metrics and results (Deo, et al. [5]).

5.2.1. Creativity Assessment by Alternate Uses Test (AUT) and ShapeStorm (SS) Exercise

The study had two different exercises for the participants, an Alternate Uses test (AUT) and a ShapeStorm (SS) Exercise. AUT is a well-established creativity test to assess divergent thinking. It has origins in psychology, but it has been used in the engineering or design context (Kudrowitz and Dippo [13]). The task statement for this exercise (Figure 7, left) was to "Come up with as many ways to use a common metal paper clip as you can in two minutes." ShapeStorming is a visual divergence reasoning exercise developed by (Sosa, et al. [23]). This exercise is specifically designed to measure visual divergence instead, which might be more relevant in engineering and design (Sosa, et al. [23]), or at least complementary to the standard alternate uses test. The instruction (Figure 7, left) was to "Arrange any two triangles to generate as many unique compositions of two overlapping triangles as you can. You can scale and turn the triangles. You have two minutes." The time allotted for the ShapeStorm exercise was changed to two minutes compared to the fifteen minutes in the original article. We did this to ensure the tasks participants performed were comparable in terms of time available. Unequal time allotted for the different tasks would void any findings, introducing unwarranted time biases. Reducing the time available for the ShapeStorm eliminated that bias.

The experiments were performed in a pre-post manner (Figure 7, center). Two primary groups, namely the AUT group and the ShapeStorm group were created by distributing the two different pre-course tests to every other student to avoid two adjacent participants with the same test. The time of two minutes to complete the task was strictly monitored. We only collected student IDs to keep track of them in the post-test. No other personal data was collected.

After the pre-course tests the ARTS-ENG Project Course 2019 was held as described above. The team that administered the pre-course tests was not involved in the teaching, and did not change, modify, or intervene in any aspect of this course. So, the course was run independently, and no group-level information was collected and/or exchanged. At the end of the ARTS-ENG Project course, the ideation exercise was repeated as described in the pre-intervention test. The tests were handed out randomly again, such that every alternate student completed the alternate uses and the ShapeStorm exercise at the end of the course. The student IDs were used to link the pre- and post-tests.

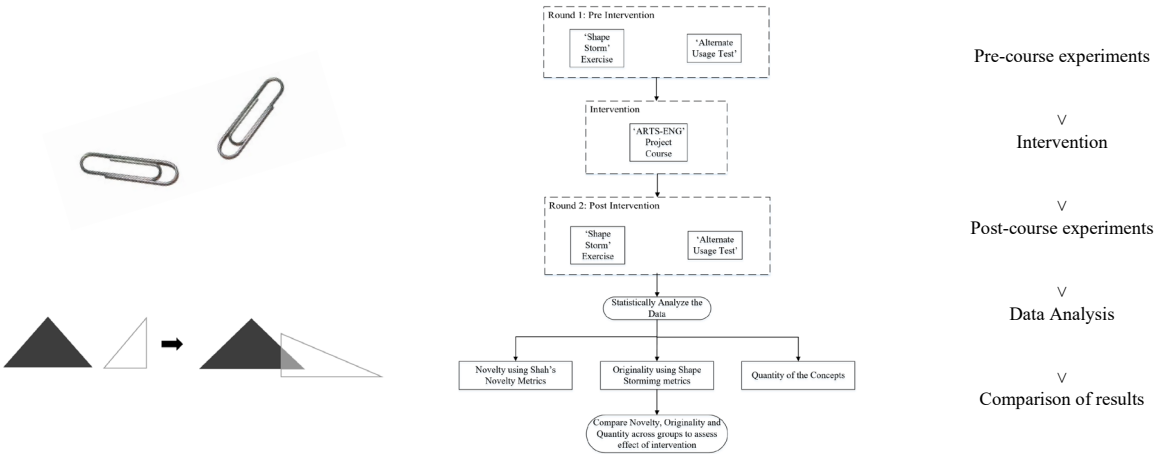


Figure 7: Alternate Uses test (AUT) with paper clips and a ShapeStorm (SS) Exercise with overlapping triangles (left); Alternate Uses test (AUT) and ShapeStorm (SS) Exercise in pre-post-course manner and the methodological workflow (center and right)

5.2.2. Results from the Alternate Uses Test (AUT) and the ShapeStorm (SS) Exercise

In particular, we assessed Originality, Novelty, and Quantity. Primarily we had two groups, one group performed ShapeStorm exercise, and another Alternate uses test. These two tests were administered in a pre-post manner. Out of two primary groups, we identified participants who performed the same test, either ShapeStorm exercise or Alternate uses test, in pre as well as post phases. The ShapeStorm exercise was for the originality assessment; however, we also applied Shah's novelty metrics to calculate the novelty score. In total six groups were analyzed. The specifics of each group are shown in Table 1. The study had no control group, and therefore, we did either between groups or within-group assessment.

Table 1: Group Notations and Test Particulars

Group Notation	Creativity Test	Analysis Type
G_{ANBG}	**A**lternate Uses Test: **N**ovelty	**B**etween **G**roups
G_{SOBG}	**S**hapeStorm: **O**riginality	**B**etween **G**roups
G_{SNBG}	**S**hapeStorm: **N**ovelty	**B**etween **G**roups
G_{ANWG}	**A**lternate Uses Test: **N**ovelty	**W**ithin **G**roup
G_{SOWG}	**S**hapeStorm: **O**riginality	**W**ithin **G**roup
G_{SNWG}	**S**hapeStorm: **N**ovelty	**W**ithin **G**roup

According to the results presented in the previous section, the ARTS-ENG Project course seems to have improved students' creativity if measured by the alternate uses test but not with the ShapeStorm exercise. The impact of the ARTS-ENG project course on students' ability to produce novel concepts

was investigated by exploring divergent thinking. This was done with the help of Alternate Uses test, a task demonstrating divergent thinking in written form. The Alternate Uses test produced novelty score. For G_{ANBG}, the study showed that the participants produced statistically significantly novel concepts after the course. A similar trend can be observed for the within-group analysis of G_{ANWG}. These insights helped to realize that, during the ARTS-ENG Project course, students' divergent thinking has improved, and the Alternate Uses test captured this progress. We also calculated the novelty score after the ShapeStorm exercise and found that improvement in the novelty score was statistically insignificant. We noticed this finding with two groups, G_{SNBG} and G_{SNWG}. The mean novelty had slightly increased for G_{SNWG} from pre to post, but for the G_{SNBG} group, it decreased from pre to post-test. After analyzing novelty, we analyzed the originality but G_{SOBG}, and G_{SOWG} showed statistically insignificant improvement after the course. The ShapeStorm exercise showed a rather different trend compared to the Alternate Uses test. Since the students underwent many visual ideation exercises to reach their final project, we expected the course to make a positive impact on visual divergent thinking, but the visual form of the ShapeStorm exercise could not capture that creativity. It is argued that the dramatic cut from originally 15 to a 2-minute ShapeStorm exercise might have been too liming to the students, and furthermore it might have led to a ceiling effect rather than proving the ineffectiveness of the intervention. Contrary to the original ShapeStorm exercise, where the metrics is explained to the students before conducting the exercise, this was not done in the present 2-minute ShapeStorm exercise. Plus, drawing is a comparably time-consuming process, although the task was simple. Finally, participants created many shape compositions violating the condition of overlapping triangles, as the participants were not trained previously. The unconscious violation of conditions of drawing geometries that were void, was most likely impacting the overall originality score. In the overall solution generation, we did not notice statistically significant improvements. However, a larger quantity of concepts in the alternate uses test compared to the ShapeStorm exercise resulted in a better novelty score.

6. Discussion

In 2016, the ARTS-ENG Project Course has been established as a major experiment at Aalto University, Finland. A Synthesis Studio, a platform for multidisciplinary collaboration between the Schools of Arts, Design and Architecture, and the Schools of Engineering has been installed as a consequence of the respective study report "ARTS+ENG, Future Collaborative Academic Models at Aalto". Since its introduction, the course underwent a constant transformation from disciplinary oriented, thematic baskets to the "discipline-free" topics of "Zero Gravity", always in mind that its pedagogic intent is to lay an early foundation for the formation of trans- and multidisciplinary skills in future levels of study.

The new living strategy at Aalto University "Shaping a sustainable future" came into effect on 1 January 2021, and the three cross-cutting approaches – sustainable solutions, radical creativity and entrepreneurial mindset – are guiding Aalto´s actions. With this paper, we were looking into the ideas of creativity, radical thinking and radical creativity, which is about empowering people with a basic, natural skepticisms and by allowing to question the world around including the predominant social and political discourses found in society. Radical thinking has been adopted by Aalto´s engineering disciplines in research and teaching, including its forerunner the ARTS-ENG project course "Zero Gravity". In 2019, the course was accompanied by creativity tests, an Alternate Uses test (AUT) and a ShapeStorm (SS) Exercise, investigating the course´s impact and its significantly positive effect on students' creativity.

Despite its challenging pedagogical and logistic tasks, the ARTS-ENG project course "Zero Gravity" is offering unparalleled opportunities to create multiple cross connections for students´ education and future careers, and to have positive environmental and societal impact.

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