International Journal of Engineering Education Vol. 33, No. 2(A), pp. 538–547, 2017
Printed in Great Britain
0949-149X/91 $3.00+0.00

Imparting Soft Skills and Creativity in University Engineering Education through a Concept Designing Short Course*

KAYOKO NOHARA, MICHAEL NORTON and ERIKO KAWANO
Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo, Japan 152-8550. E-mail: nohara.k.aa@m.titech.ac.jp

Universities need to add a range of soft skills to the range of technical specialities provided in engineering education to respond to demands for engineers who can solve complex problems in an international working environment, and which recognises social and environmental issues (and associated stakeholders). Soft skills related to creativity, communication and teamwork abilities are often mentioned. But in addition, engineers planning to work for a company competing in the global market need to be aware of the increasing competition on non-performance factors incorporating artistic and aesthetic considerations into the design process. This paper describes a novel approach being used at Tokyo Institute of Technology by partnering with Musashino Art University to develop a 'concept designing' course where engineering and arts students work together in a short intensive course to develop a design based on an initial abstract concept. The 5 years of experience on this course allow us to assess the range of skills and experience provided against the initial objectives and student outcomes of the course. We conclude in this paper that such cooperation between engineering and arts has significant benefits for the creative process and in developing students' soft skills.

Keywords: engineering education; soft skills; creativity; communication; design

1. Engineering education in Japan—current challenges

Japan assigns a high priority to engineering education, producing 168,215 engineering graduates in 2015 [1]. This supports the continued importance of manufacturing in the Japanese economy where manufacturing contributes 27.3% of GDP compared with 19.2% for USA and 24.9% for the EU average. Japanese competitiveness as measured by the WEF global competitiveness index remains among the top 10 [2] but is under pressure from both developed and developing countries' industries; indeed, recent years have seen some of the leading global names which dominated Japanese exports in the past face severe challenges to their survival (Sony, Sanyo, Toshiba, Sharp etc.). Such trends have led to various reviews of how Japan should adapt its education system to help address global challenges [3, 4] where common themes emerge on the importance of strengthening creativity, language skills, teamwork skills and internationalisation in engineering education.

Similar conclusions have emerged from reviews of engineering educational needs in other countries. Klukken et al. [5] refer to the need for an increased emphasis on communication skills, teamwork and open-ended problem-solving in engineering education. More recently, Pasha-Zaidi [6] notes that graduates of engineering programs in today's globalized economy must be able to apply their technical knowledge in team-based environments where flexibility, communication, and cooperation are needed to solve problems that do not necessarily have well-defined technical boundaries. Globalization's effects on the work environment for engineers in all countries have thus added 'soft skills' to the continued demand for technical knowledge in various countries [e.g. 7–9]. Such skills include 'ability to learn', 'teamwork' and 'communication' and 'problem solving' [10], as well as coping with the increasingly interdisciplinary nature of engineering-where new graduates work in multidisciplinary teams that require cooperation in order to tackle problems straddling boundaries. Such boundaries include cultural ones where 'cross-cultural' (not just the ability to operate in a foreign language) skills are also desired in global engineers [11].

Calls for such skills are in parallel with the evolving challenges engineers are expected to help solve. Increasing complexity of fundamental technologies (materials, ICT, systems engineering etc.) combine with society's expectations that social and environmental needs should be met at the same time as those of the customer. This in turn leads to a demand for creative problem solving while interacting with different stakeholders. Such skills thus need to be added to the teaching curricula for engineering students of any specialisation, creating a demand for methods and techniques to facilitate creative problem solving processes [12]. Creativity, in turn is seen by Liu and Schonbetter [13] as requiring

* Accepted 10 January 2017.

fluency (ability to generate many ideas), flexibility (ability to change the form, modify information and change perspectives), originality (ability to generate unusual or novel responses) and elaboration (able to embellish an idea with details), while team working attributes include: openness, flexibility, non-conformity, willingness to take risks, tolerance of ambiguity and confidence in one's own convictions.

In Japan, these demands may be supplemented by a widening of the role of corporate engineers as a result of competitiveness pressures. In the past, it may well have been the dominant career pathway to graduate from a technical university and work in research, development, engineering or technical support departments applying specialist skills founded on the basic engineering education. The challenges for the engineer would be technical capability, function, efficiency, energy consumption and so on. However, the severe global competition which has led to the challenges facing Japanese companies in previously dominant markets, leads to additional pressures to differentiate between rival products. Here, it has long been recognised in marketing departments (e.g. [14]) that market success for new products is dependent on physical form and design, as well as technical performance specifications. A good design will communicate to the consumer a message or image to attract them so that, given the choice between two products of similar price and function, consumers will buy the one they consider more attractive. This has lead product designers to bring together engineering with art, psychology and behavioural sciences (e.g. [15]).

One means of responding to current industry expectations is to provide experience to engineering students of design perspectives outside their fields, and to this end Tokyo Tech has created an 'Science and Art Laboratory' bringing together science and art (http://creativeflow.jp/en) to support cross-disciplinary education through collaboration with Musashino Art University (MAU). A short intensive course has been developed to particularly focus on interaction between art and engineering in design, while also encouraging creativity and soft skills development. While researchers have reported the impacts of intercultural differences in a design setting [e.g. 16] we consider bringing together arts and engineering/science students on a common project is a novel approach; this paper thus describes the background, implementation and results of this module on "concept designing".

2. The concept designing course

The 'concept designing' course is intended to provide students from both universities with cross-disciplinary experience in cooperative design. The course is intended to simulate the scenario where designers and engineers work together as teams for creative tasks such as product development. Team members must be able to objectively identify and utilize each other's skill sets, and resolve any issues arising from miscommunication in order to optimally facilitate their tasks. Since Tokyo Tech students tend to communicate in the language of science and technology, and MAU students the language of art, cross-discipline communication is also imperative.

The course is a one week intensive course where teams of students from both universities work on a general theme provided at the start, discuss and develop a sophisticated concept, and express this in an object put together in the Tokyo Tech Collaboration Center for Design and Manufacturing. As described by Nohara and Kawano [17], the course follows the format:

Day 1: the course's theme is introduced and guidance given on effective communication, techniques such as brainstorming, and artistic guidance about what students should consider when designing. Groups start their work by brainstorming based on the theme assigned.

Day 2: Products of the brainstorming are developed into a concept which is to be expressed in some form. Background lectures are given on available design materials and ways of using them. During the process, instructors are on hand to provide constructive comments.

Day 3: the groups give an interim presentation on their concept. After feedback from instructors and students from the other teams, they proceed to construct their design during the remainder of Day 3 and Day 4.

Day 5: Groups give their final presentations in an open forum including external assessors.

The progress of the teams' work is recorded by video, as are the lectures and final presentations. This audio-visual data has been supplemented by interviews and questionnaires after completion of the course.

Courses conducted since 2012 are shown in Table 1, together with the course theme, the design concept of each team, and a simple explanation of their intention.

3. Results and analysis

As can be seen from Table 1, student groups developed a diverse range of concepts from the same initial (deliberately vague) theme. The resulting works ranged from short videos to collections of various art forms (such as pictures or sculptures) or models or equipment fabricated from available

Table 1. Concept designing courses conducted since 2012

Concept designing Course	Theme	Concepts developed by each team	Comment
1 2012 (July)	Love letter	Condensing feelings	Feelings represented by blocks in a sculpture concentrating to a single point.
		Memories melted into place	Sculpture symbolising fusion of 7 different feelings.
		The partner inside me	Sculpture of a large eye inside which is the shape of the loved one.
		The line through the environment I made but cannot see	Invisible spotlight around the person representing the sense of enhanced identity of someone in love.
2 2013 (July)	Adult and child	Parent and child sushi	Clothes for a parent made out of rice, and clothes for children made out of toppings. When they hug, they become one sushi.
		Time's road and children's fragments	Works of art representing small things which remind of childhood.
		You finding object (UFO)	UFO-shaped objects which respond to touch in different colours signifying different stages of childhood.
		Product to span time and trigger adult-child dialogue	A traditional wooden container for pickling vegetables (given by parents on a child's marriage) to signify longevity and preserving childhood memories.
3 2014 (July)	Repetition	Time interval	A three-dimensional model representation of time.
		Mother's love	A 'Russian Doll' of bento boxes to signify daily lunch boxes prepared by mother over and over again.
		Repetition in parenting	A box of miscellaneous toys representing the perpetual repeat of taking out to play and tidying up afterwards.
		Burning - repeating unrepeatable actions	Repeating the partial burning of cardboard is a repetitive process but all are unique, so not repeatable.
4 2015 (July)	Black square	Weariness	A movie of a person walking and stopped by a black square (as in the exit button on a movie player).
		Portion dimmed	Artistic configurations of black squares and shapes which are intermediate between black and white.
		Irony of reaction	Mathematical interpretation of black square expressed in movement art.
		Behind blackness	A display box including 8 imaginative ways of showing blackness.
5 2016 (July)	Long thing	Destruction of length	Length depends on point of view and structure. 5 examples of how length can be eliminated.
		Book of water	Starting with the phrase "it will take a long time to talk about it", saw length as 'river' of time. Made a 28m long collection of art and text.
		Kaiten sushi	Saw the rotating sushi belt as never-ending representation of 'long' meaning 'eternal'.
		Length structured to your own life	Saw length as constructed from shorter component parts, and analogous to an individual's life being the sum of all their experiences. Constructed a graphic representation of this.

materials of paper, polystyrene, cardboard, wood, containers etc. Some end products were primarily art (sculpture, painting) while others involved engineering (e.g. rotating tables, model of circulating water).

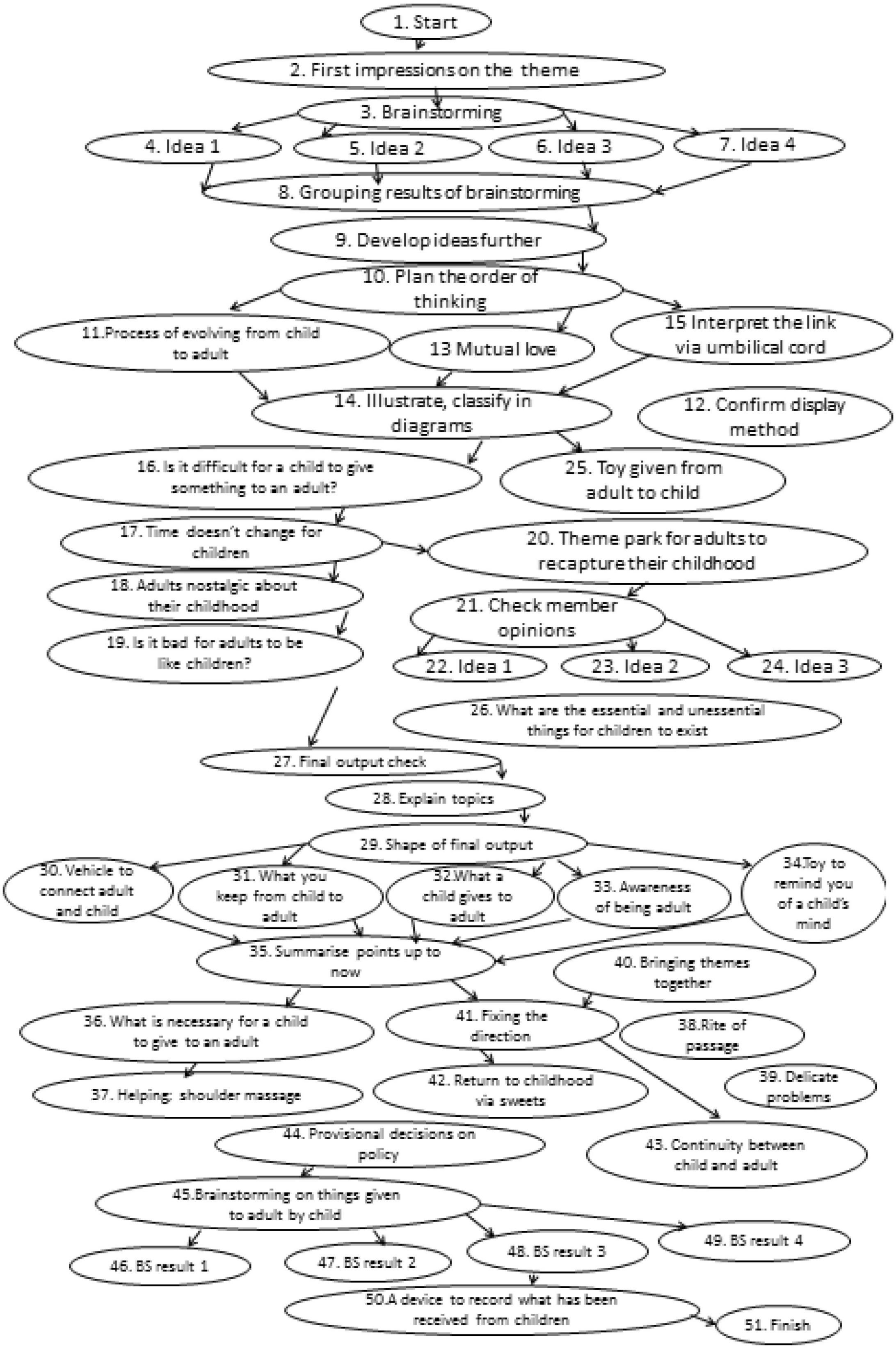
We now consider the outcomes of the courses based on each year's video research, questionnaires and two special supplementary analyses:

- In 2013, the process followed from the initial theme to final outcome was studied in detail based on discourse analysis and a detailed questionnaire. The actions of the teams comprised of both arts and engineering students (mixed group) were also compared with 'control' groups comprised of just engineering students (engineering only group).
- In 2016, students were asked to maintain a 'creativity log' which should record the origins of what they regarded as creative steps during the process. These were completed after each day (Day 1 of initial brainstorming; Day 2 developing the idea towards the mid-term presentation; Days 3 and 4 involving transforming the concept into a design object).

This data lead us to make a number of observations from the perspectives of creativity, communications and personal skills development.

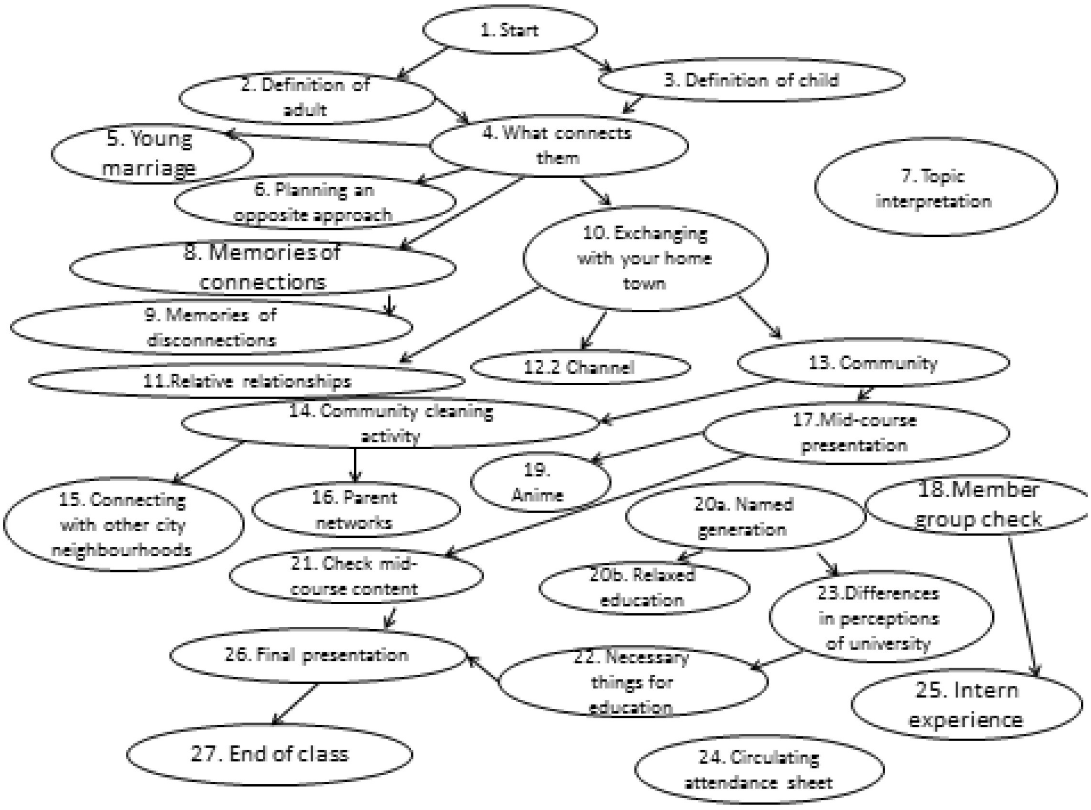
3.1 Creativity

The segment analysis of the 2013 course applied methods which allow discourse to be structured according to the purposes of conversational segments, separated by phrases indicating a change in the discourse direction [18]. Yamazaki [19] found that the mixed groups deployed complex pathways from the original discussion to the final outcome, involving multiple stages in which ideas diverged before converging again towards the next step (Figure 1a shows the results of this analysis for one of the mixed teams). The mixed group also



(a) Mixed Team

Fig. 1a. Tracking the development of the concept design through discourse segment analysis. Source: Yamazaki [19] which also includes results for two other teams (one mixed and one engineering only).



(b) Engineer-only Team

Fig. 1b. Tracking the development of the concept design through discourse segment analysis. Source: Yamazaki [19] which also includes results for two other teams (one mixed and one engineering only).

displayed a higher proportion of abstract discussions (Table 2) and even periods of confusion as a result of communication challenges between the art and engineering fields. In contrast, the groups comprised only of engineers were more logically based, abstract themes were fewer and the flow from the original concept to the final product much simpler (shown in Figure 1b).

Comparing the results of the segment analyses in Figure 1 reveals a stark difference in the complexity of the flow between mixed and single discipline teams. Not only were the discussion topics more numerous in the mixed teams, but the contents of each stage show a dominance of substantive idea discussions, compared with a number of more mechanistic issues (e.g. how shall we prepare for

Table 2. Degree of abstract content in the main items discussed in the 2013 concept designing course (theme of "adult and child")

Specific themes (mixed teams)	Being patted on the shoulder or promised things; adult and child definition; touching nature and returning to a child's mind; the difference in feeling between adult and child; going to Disneyland; toys used to play with and sweets; believing in Santa Claus; having magazines focused on adolescents; exchanging contact details.
Abstract themes (mixed teams)	Are children born with completeness and do they lose some of it as they grow?; expressing adults and children through a picture; drawing the relationship in a picture; the boundary between adults and children; connecting me now with me in the past; restoring relations which have become broken; folklore village; a relationship like a never-ending loop; a cup containing the image of links; the growth process a bit like a broken suspension bridge; pretentious child; a place which returns the feeling of childhood; the image of adult and children's body; stopping my peace of mind.
Specific themes (engineer-only teams)	Adult and child definitions; park, university; student friends with children; conversations about experience of childhood; memories of playing in the community hall; preparing for festival dancers; accessing channel 2; memories of cleaning the village; friends in the city; the strength of parents' networks; confirming the choice of subjects for school; manga on holidays; discussion of internships.
Abstract themes (engineer-only teams)	Existence and trust; concerning communication with others; meaning of anime lyrics; giving names related to the generation; accepting education; learning outside classes.

the next presentation) in the engineering-only teams. This suggests that mixing engineering and arts students contributes positively to both the number and originality of ideas.

A provisional hypothesis thus emerges from the segment analysis that mixing of arts and engineering students makes a positive contribution to creativity. This was further examined in the 2016 course's creativity log which showed that:

(a) The number of creative steps recorded by each of the 4 teams was much higher (by a factor of 2 to 3) in the first two days which comprised the brainstorming and concept generating phase; and reduced once the team entered the stage of implementing and expressing their concept.
(b) All 4 teams showed that both engineering and art students contributed to a similar degree to the creativity process (ratios of engineering and art contributions in the 4 teams were: 53/47; 46/54; 43/57; 49/51 respectively.) In addition, 2 of the 4 teams assigned a limited number of creative steps as originating jointly between engineering and art fields.

Based on the students' own assessments of creative steps and their origin therefore, it appears that both engineering and art fields contribute separately as well as jointly to increase the number of creative steps- consistent with the differences observed between mixed and single discipline teams in Yamazaki's study.

3.2 Communication

Analyses of conversations in all of the courses show that engineering students tend to put more emphasis on logical thinking and proceed in incremental steps, while the art students depend more on feelings and perception for their judgements, with a greater tendency to introduce a new idea in discontinuous steps. Similar fundamental differences have also been observed in written modes, with engineers using words to express ideas during brainstorming whereas art students showed a strong tendency to use symbols or pictures when writing down ideas-sometimes with a strong, even provocative, visual impact. Moreover, we observed a tendency for the engineers to move towards the choice of the object following the flow of their logical thinking, whereas the art students were more likely to think first about what they could actually make and then rationalise a connection with the design theme. Nohara and Kawano [17] also examined the results of the courses up to 2014 from the perspective of translation theory and evaluated the extent to which students' creative skills were strengthened through intercultural communication. They noted that in general, there was a tendency for the Tokyo Tech students' science and technology knowledge to be high but abilities in verbal expression to be lower. On the other hand, art students had a stronger ability to imagine and express themselves, but their logical thinking was weaker.

These different qualities (summarised in Table 3) could provide complementary strengths and weaknesses in a team. Moreover, students used various different social expressions (including specialised language for their respective fields) and also different communication styles. The workshops thus required Tokyo Tech students to think about how to communicate their technical knowledge in ways which the art students could understand. Equally, the art students are used to every day art and design language which they have to transfer to more general language in order to convey their thoughts to Tokyo Tech students. Even when using the same words, there may be different meaning or societal images contained within them, depending on the receiver's experience.

Such practical exercise embeds the realisation that whatever words are used, when the other party doesn't share the same lifestyle or culture; interpretation may be different so that logical argument cannot progress smoothly. In this sense, there are similarities with the situations studied by Badke-Schaub, Goldschmidt and Meijer [20] who found that creativity was enhanced through cognitive conflict in teams with different disciplines, cultures and language. The particular feature of this course is that students have to transform their ideas into a physical form, so that even if they do not notice differences in interpretation at the discussion stage, this soon becomes apparent as they start to make their exhibits. The inherent misunderstandings, failures, and repeated needs to adjust are just some of the experiences which teach more effective communication.

Table 3. Summary of differences observed in behaviour of engineering/science and art students

Attribute	Engineering/science students	Art students
Concept vision	Theoretical, specific	Abstract, general, visual object
Communication style	Word-based	Visual; symbols, pictures
Thinking	Logical, incremental, linear	Feeling-based, discontinuous
Word usage	Specific meanings, defined	Vague, not well-defined
Approach to object	Logic leads to a specification for the object	What can we make limits the object design options

Nohara and Kawano [17] noted that effective communication between diverse groups of different specialisms and cultures poses similar challenges to those in translation and that translation theory could thus form a theoretical framework within which to analyse group communication processes. In translation, three types are recognised: translation between languages (e.g. Japanese to English), translation within a language (e.g. translation of scientific terminology to more commonly used words), and thirdly translation between symbols (e.g. between those used in science and those used in art). Examples of all three types of translation were found in student discourses, including cases when limits were encountered in the first two types of translation and students turned to symbols to overcome the limits of words. By giving the students experience in both verbal and visual explanations, abilities to communicate and discuss various concepts may be assisted.

3.3 Personal and soft skills development

Questionnaires and structured interviews after the workshop were also conducted to identify impacts of the course on students' personal skills. Questions were deliberately open (Table 4) and analyses of the results from 2011 to 2014 (total 38 participants) found that around 80% reported some change in their thinking, both in understanding communication and design sense. None reported having found the course lacking any value.

Nohara and Kawano [17] extracted comments from the basic questionnaires to give a qualitative picture of individual student's perceptions on communicating between fields, the interaction between science and art, and on changes in their design thinking (Box 1). These comments suggest that students appreciated the difficulty of discussion between very different fields and sometimes lost

Table 4. Open questions in post course questionnaire

1. What were the gains from participating in this course?
2. What were the most interesting parts/most difficult parts?
3. What changed in your view of design?
4. What do you now think of as "concept"?
5. What was the point in the discussions within the team that was most intense?
6. What techniques were useful for gaining ideas?
7. How did communication proceed during the actual process of constructing the object?
8. What were the good and bad points of the team?
9. What were the good and bad points of you personally?
10. Who did what and who contributed most?
11. Did the final object reflect the team's discussions?

Box 1 Comments which illustrate reactions and perceptions of participants

(a) On communicating between fields

- I appreciated the different perceptions of design between people engaged.
- I felt it was quite difficult communicating with someone whose basic sense was different; even if we shared common ground at the beginning, as the discussion progressed different ways of thinking came out and multiple repeats were often required.
- Sharing thoughts with another person, illustrated the difficulty and interesting aspects.
- The logic-focused Tokyo Tech students and the feeling-focused art university students was a significant difference in thinking.
- It was an experience allowing me to understand the different thinking and knowledge of design from different viewpoints.
- I saw that different ways of thinking and this helped deepen our knowledge;
- As the discussion advanced, we sometimes lost our way but from that various ideas emerged with flashes of inspiration.

(b) On the interaction between science and art

- I appreciated the limits of just piling up theories, and the importance of parts which could not be expressed logically. Bringing together science and art pushed my strong points to their furthest limits and made me think of using processes I hadn't considered up to now.
- Bringing together subjective feelings and logical thinking made me realise this would release a substantial power.
- The scientist's way of thinking is that there is only one meaning associated with a particular word or concept. However through the workshop you realise that vague expressions are also good; also that different interpretations can be enjoyable.
- I could detach myself from my own specialist field, see things from my different point of view and enter a mixed space of diverse communication style. Somehow in design an important answer was borrowing the perspectives of various people.
- I noted the importance of freely imagining and freely expressing. The ability to extract something from these wide viewpoints is an important part of ability to creatively express.
- By being exposed to various perspectives, I was able to think about what it means to express words through art, whether a piece should be easily interpreted, and how much emotion should be expressed.
- This was a fruitful experience because I could meet people who had completely different approaches to coming up with ideas than I do.

(c) On changes in design thinking

- My thinking changed from designers just being looking at a simple external image and beauty, to recognising that it had to include the solution to a variety of problems.
- My thinking changed to thinking of design as a means of easily communicating the value to the onlooker.
- Things associated with design ('first try drawing it') and you realise the importance of moving your hand and seeing the process of going from idea to concept. Words are not sufficient - you need visual expressions as a communication tool.

their way, but were able to adapt to this situation. Students from both universities appreciated the strengths of diversity between the two fields of science and art; moreover there was evidence of a shift away from seeing design as just being about a superficial image, to a deeper understanding of the interaction between design and function, and the component parts; moreover that designs can convey feelings and shared values.

4. Discussion

We now consider the results against the theoretical framework outlined in the introduction. Considering first the creativity process, Liu and Schonwetter [13] characterise the creative process as containing four phases- preparation, generation, incubation and verification. The preparation phase includes defining, reformulating and redefining the problem or question. The generation phase is equivalent to brainstorming which involves exploring various possibilities and identifying potential concepts. The incubation phase is where the mind is given free time in which subconscious thinking can refine initial ideas and perhaps develop additional insights, while the verification phase analyses the ideas and develops specific plans for experiment or development.

Considering the concept designing course against these criteria, the initial preparation and brainstorming on Day 1 can be seen as the preparation and generation phase, the next two days are the incubation phase where initial concepts are developed and refined, while the verification phase relates to the challenge of converting the concept into a physical form in a way in which it can be explained to the final audience.

Many blocks to creativity have also been proposed; e.g. a fear of the unknown, fear of failure, hesitation to contribute in group work or lack of confidence, fear of appearing superficial or of having one's proposals debated by others [21]. Creative expression also requires an environment of psychological safety and freedom which is free of others' punitive evaluations [22]. This environment was created through some of the introductory lectures, a strong emphasis on there being no right or wrong answers, and monitoring by the staff and facilitators.

Regarding the contribution of the mixed teams on the 2013 course to the creativity process, the frequency of abstract discussion has already been noted. Nagai and Noguchi [23] have associated a higher proportion of abstract discussions with the emergence of creative ideas, again suggesting that mixing the disciplines contributes to creativity. Increased creativity can also be anticipated from Simonton's [24] creativity model where scientific creativity is held to be a combinatorial process (involving the generation of chance combinations). Increasing the number of possible "phenomena, facts, concepts, variables, constants, techniques, theories, laws, questions, goals and criteria" [24] will cause the total number of potential combinations to increase. The concept designing course brings together students from two completely different domains (engineering/science and art) and provides an intense environment for one week in which students are encouraged by the course's organization to straddle these two domains- thereby increasing the number of possible ideational combinations. It is thus to be expected that levels of creativity should be higher since by chance alone, increasing the size of the fields devoted to a specific set of ideas must enhance the odds of generating the best ideational combinations. The creativity log of the 2016 course suggested that each domain (art and engineering) was contributing at very similar levels to the creativity process.

In terms of personal skills, the Japanese language allows many processes which incorporate thoughts and feelings in expressions and these are often used in conversation. For example, rather than record the objective fact that "A-san came on Tuesday", a personal and subjective interpretation is often added—such as "as I expected A-san came on Tuesday". This 'subjectification' or 'personalisation' is not however encouraged for science and engineering students, who are taught at university to express matters objectively. Experience and skills in using subjective and personalised expressions appropriately are thus weak whereas in contrast, art students use subjective expression as a rich part of their conversation. From the point of view of science and engineering researchers investigating the results of experiments or surveys, a perspective which personalises the objective facts' meaning and interpretation, and the associated language, may also be desirable and collaboration with art students may thus provide training in this power of expression. In particular, the differences between engineering and art-related thinking becomes clearer, as has been expressed in student responses.

As Simonton [24] notes, artistic creators often rely heavily on incongruity, implausibility, ambiguity, suggestion, and illusion, whereas scientific creators must depend on consistency, plausibility, clarity, implication and explicitness. The concept designing course makes students aware of potential inputs from outside their field and encourages them to consider them on a level equivalent to their own contributions. Such openness to experiences outside their field, and the associated interdisciplinary exposure increases the odds they might chance upon facts or concepts that turn out to be relevant to one of their current projects. Taking part in the workshop and its exposure to completely different fields may well trigger interests which enhance their openness to experience and thus make contributions to future creativity.

5. Conclusion

The concept designing course was intended to simulate a scenario where designers and engineers work together as teams for creative tasks such as product development. Team members must be able to objectively identify and utilize each other's skill sets, and resolve any issues arising from miscommunication in order to optimally facilitate their tasks. Since Tokyo Tech students tend to communicate in the language of science and technology, and MAU students the language of art, cross-discipline communication is also imperative. Although this work's conclusions are limited by the short duration of the course (1 week) and the limited number of students who have been able to participate (a total of 78 over 5 courses), we have found evidence that even such a short intensive course straddling boundaries between engineering and art can contribute to communication, creativity and team working skills essential for the likely role of engineers after they graduate. As far as the engineering students are concerned it provides an opportunity to broaden views beyond their own fields, and also nurtures the soft skills to operate in a global and team-based environment, with the collaboration with art students bringing design-relevant perspectives alongside technical skills.

References

1. World Economic Forum, 2015. Human Capital report 2015.
2. World Economic Forum, 2015a. Competitiveness ranking, 2015.
3. Cabinet Office, 2007. Innovation 25. http://japan.kantei.-go.jp/innovation/interimbody_e.html (accessed 10 August 2016).
4. Cabinet Office, 2012. Strategies for global human resource development (in Japanese). http://www.kantei.go.jp/jp/singi/global/1206011matome.pdf (accessed 10 August 2016).
5. P. G. Klukken, J. R. Parsons and P. J. Columbus, The creative experience in Engineering practice: Implications for Engineering education, *Journal of Engineering Education*, **8**(4) 1997, pp. 133–138.
6. N. Pasha-Zaidi, Developing a professional skills matrix for engineering students, QScience Proceedings (Engineering Leaders Conference) 2015, **9**. http://dx.doi.org/10.5339/qproc.2015.elc2014.9 (accessed 10 August 2016).
7. S. Kumar and J. K. Hsiao, Engineers learn 'soft skills the hard way. Planting a seed of leadership in engineering classes. *Leadership and Management in Engineering*, **7**(1), 2007, pp. 18–23.
8. H. Baytiyeh, Disparity between College Preparation and Career Demands for Graduating Engineers, *International Journal of Engineering Education*, **28**(5), 2012, pp. 1221–1231.
9. A. Sousa and A. Mouraz, Promoting 'Soft Skills' from the Start of the Engineering Degree and the Case Study of the Special 'Projeto FEUP' Course, *International Journal of Engineering Education*, **30**(6B), 2014, pp. 1539–1548.
10. S. H. Pulko and S. Parikh, Teaching 'soft' skills to engineers, *International Journal of Electrical Engineering Education*, **40**(4), 2003, pp. 243–254.
11. C. Del Vitto, Cross-Cultural "Soft Skills" and the Global Engineer: Corporate Best Practices and Trainer Methodologies," *Online Journal for Global Engineering Education*, **3**(1), 2008, Article 1.
12. R. Vidal, Creativity for Engineers, 2003, Technical University of Denmark.
13. Z. Liu and D. J. Schonwetter, Teaching creativity in engineering, *International Journal of Engineering Education*, **20**(5), 2004, pp. 201–208.
14. P. Bloch, Seeking the ideal form: product design and consumer response, *Journal of Marketing*, **59**(3), 1995, pp. 16–29.
15. A. T. Purcell and J. S. Gero, Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology, *Design Studies*, **19**(4), 1998, pp. 389–43.
16. F. Détienne, M. Baker, M. Vanhille and C. Mougenot, Cultures of collaboration in engineering design education: a contrastive case study in France and Japan, *International Journal of Design Creativity and Innovation*, **5**(1–2), 2016, pp. 104–128
17. K. Nohara and E. Kawano, Science and Art/Design Education for Engineers and Scientists for the Purpose of Nurturing Creativity, *Journal of Japanese Society for Engineering Education*, **63**(1), 2015, pp. 87–94 (in Japanese).
18. K. Takeuchi, Units of Analysis for Conversation, Dialogue and Discourse Studies: Discourse Segment, *Journal of Japanese Society for Artificial Intelligence*, **23**(2), 2008, pp. 277–282 (in Japanese).
19. T. Yamazaki, Analysis of communication and output in cooperation between different disciplines, MA Thesis, Tokyo Institute of Technology (in Japanese).
20. P. Badke-Schaub, G. Goldschmidt and M. Meijer, How does cognitive conflict in design teams support the development of creative ideas? *Creativity and Innovation Management*, **19**(2), 2010, pp. 119–133.
21. D. J. Treffinger, S. G. Isaksen and K. B. Dorval, Creative Problem Solving: An Introduction, Prufrock Press, Waco, TX (2000).
22. C. Rogers, Towards a theory of creativity, *A Review of General Semantics*, **11**, 1954, pp. 249–260.
23. Y. Nagai and H. Noguchi, Thinking type of drawing design students and relationship to creativity: the role of drawing in the design creativity process, *Design Research*, **48**(4), 2001, pp. 131–138.
24. D. K. Simonton, *Creativity in science-chance, logic, genius and Zeitgeist*, Cambridge University press, 2008.

Kayoko Nohara is Professor of Translation Studies and Science Communication at the Transdisciplinary School of Science and Engineering, the Tokyo Institute of Technology. She holds an MA in Japanese Linguistics from Gakushuin University, Tokyo, an MA in Modern History and PhD in Translation Studies from University of Oxford. Her publications include Translation Studies in Discussion (2014) and, as co-author, Kagakugijutsu no genba to shakai o tsunagu kagakugijutsu communication nyumon (Introduction to Science and Technology Communication).

Michael G Norton has a BSc and PhD in chemistry from Bristol University (1968). He worked for industry and the UK government science service before becoming Director of the UK Parliamentary Office of Science and Technology (1989–1998). From 1998 to 2004, he was Counsellor Science and Innovation at the British Embassy in Tokyo and then Professor at Tokyo Institute of Technology, Shinshu and Tohoku universities in the fields of innovation, management of technology, sustainable development, environmental leadership and science communication. His publications cover all those fields and include 2 books (''Sustainability and business-duty or opportunity''; ''Topical themes in energy and resources''). Currently at the Transdisciplinary School of Science and Engineering at Tokyo Institute of Technology.

Eriko Kawano is currently Education/Research Assistant at the Transdisciplinary School of Science and Engineering at Tokyo Institute of Technology. She earned her MEng degree in Environmental Psychology at Tokyo Institute of Technology.