On integrating a Substantial Interdisciplinary Collaborative Element into the Classic Electrical Engineering Curriculum

[1]Gabriela Dorfman Furman and [2]Zeev Weissman,
[1,2]Electrical Engineering department, Faculty of Engineering, Shenkar College of Engineering, Design and Art, Israel

Abstract: This paper discusses a curricular path towards effective integration of interdisciplinary collaborative component into electrical engineering education. We first studied, quantitatively and qualitatively, the level of interest engineering students have in interdisciplinary studies and creative activity. We found out that students are quite interested. We continue by proposing a four-phase path towards effective integration of interdisciplinary study into the classic EE curriculum.

Keywords: *Design thinking, Interdisciplinary engineering education, project-based learning;*

I. INTRODUCTION

Engineering education is hierarchical and knowledge intensive. Historically, the engineering curriculum has been based on studying basic science and applying scientific principles/models to analysing, and solving, of technological problems.This typically leads to being confined within the boundaries of the respective core curricula structure[1]. However, recent reports on engineering education suggest improvements, needed in order to prepare engineering graduates to meet future challenges [2,3,4,5].Some of the needed improvements concern developing and usingof additional skills, outside the realm of traditional engineering study[6],in some cases, at the expense of more traditional engineering subjects.Higher education institutions understand this [7,8,9,10] and seek ways to add interdisciplinary elements & skills to the traditional engineering education.

One such skill concerns the *design thinking (DT)* process: an essential expectation from engineering graduatesis to be able to design solutions to meet user needs, and in a wider sense, various social needs [11]. DT is considered to be an effective methodology to achieve this goal. Increasingly, major corporations such as IBM and Apple, are integrating DT into their R&D process [12]. IBM, for example, uses DT intensively, and employs some 20000 engineers trained in DT. In general, Design thinking methodology consists of five steps: empathize, define, ideate, prototype and test. With the exception of prototyping, this process is typically outside the realm of engineering education. Typically, engineers, once given a task, start with a technical analysis, followed by a technical design, and then prototyping. In other words, they focus on HOW to design and build a prototype, and less on the steps that lead to the definition of what the desired prototype shall be in the first place. Designers, on the other hand, study and use design thinking as way of working. Thus, potentially, engineering students may become familiar with this useful methodology, by co-working with design peers.

Another needed skill is*teamwork*[13,14].This includes collaborating withvarious, often different, types of engineers-to-be, as well as collaborating with designers-to-be (industrial designers, architects etc.). One approach is to enhance teamwork via project-based learning.In particular, perhaps, interdisciplinary project-based learning.

Providing joint Engineering-Design courses and projects may thus facilitate innovation at the interdisciplinary interface [15], as it was previously shown that the inability to perceive and reflect different views on design may limit innovation [4,16]. Aspects of collaboration between engineers & designers typically include ideationand prototyping (functional and visual) [17]. Typically, most of it is not a standard part of engineering schools' curricula, which, arguably, focus on analysis subjects, and less on other aspects, such as human interface, functional and aesthetic ones.

From the perspective of engineering education, there are (at least) two rationales for encouraging such interdisciplinary collaboration at the undergraduate level. One concerns the fact that prototyping became more accessible in recent years, by the increasing availability of low-cost prototyping elements. Among others, this includes programmable electronic controllers (e.g. Arduino) and low-cost 3D printers. These "small R&D" enablers can facilitate a small group of motivated engineering students that have identified an interesting (and not too complicated) problem, to develop a working prototype, with minimal funding. However, to make a real product, such prototype would require integrating the various aspects of proper design, as indicated above. The second rationale concerns the fact that while engineers are supposed to design products, the vast majority of their training is actually devoted to a wide set of analysis subjects. Thus, the mindset of designing needs to be strengthened. Familiarizing with the basic aspects of non-technical design process would thus enrich the engineering training. Effective collaboration with design students seems to be a good way to achieve this, for the benefit of both sides.

In writing this paper, we have two goals:

1. To characterize students' attitude towards engaging in a substantial interdisciplinary interaction as part of their engineering education. In particular, consider this, in light of a common perception that such interdisciplinary efforts may have an unclear contribution to their future

engineering careers.

2. To chart a path towards integrating a fruitful interdisciplinary interaction into the engineering education. It consists of four phases, as discussed in detail below.

Shenkar College (Shenkar, in short) comprises two faculties, engineering & design, and a school of Arts. As such, the college provides a suitable setting for experimenting with interdisciplinary study ideas and testing their effectiveness. In recent years (since 2012), an annual Hackathon-like workshop event is happening in Shenkar. It is called *Merkaha* (Hebrew word for jam, or concoction). Detailed description is given in App. 1. In brief: it occurs during the period between winter & spring semesters and almost all 2nd year students in Shenkar participate. Engineering, design and art students meet during 3-4 days of creativity, to jointly work on projects. The event is typically composed of about fortyworkshops. Each workshop hosts students from the two faculties, and is typically guided by two lecturers, one from each of the faculties.

For the purpose of composing this paper, we used this annual event as a testing ground for students' attitude, which is critical if we intend to nurture an effective collaboration. So, during the event of last year, we have carried out a study, concerning the student's attitude to interdisciplinary collaboration and the usefulness of *Merkaha* in that regard.

In this paper, the research questions are posed, the methodology is described, and the main results are reported, and subsequently discussed

II. RESEARCH QUESTIONS

In this study, we posed five such questions:

Research question 1: to what extent are engineering students, and design students, interested in collaborating with each other?

Research question 2: to what extent do engineering students believe that such an interdisciplinary collaboration provides them with a valuable knowledge, experience, and career edge?

Research question 3: to what extent do students translate the interest they might have in an interdisciplinary collaboration, to carrying out significant joint engineering-design projects?

Research question 4: is there a curricular path to enhance this (presumable) basic interest in interdisciplinary collaboration?

Research question 5: is there a curricular path that may facilitate an effective integration of a substantial design-oriented knowledge to engineering students, so that some of it would actually contribute to their future career in engineering?

III. METHODOLOGY

The participants were asked to complete three parts of a questionnaire (Q1, Q2, and Q3), as follows: Q1 - just prior to *Merkaha*, Q2 - immediately after *Merkaha*, and Q3 - one year after *Merkaha*.

Q1 and Q2 were answered by 700 students from both faculties, and from the art department. The student proportions were 40%, 40% and 10% respectively. Q3 included a smaller group, of ~100 students.

The contents of these questionnaires were as follow:

Q1 – Since students were asked to choose a workshop related to their topics of personal interest (ones that were not part of their professional career), we may assume they were, to a reasonable degree, keen to collaborate. In Q1 they were thus asked an open question about their motivation to participate in an interdisciplinary workshop. This question gave us a baseline to evaluate the findings. The wording:

Q1a - Do you think there is a need for cooperation between designers/artists and engineers at work? If your answer is positive, explain why.

Q2 – This time the studentswere asked about their workshop experience. The purpose of Q2 was to examine the subjective perceptions and changes following the workshop. The first question of Q2 was identical to that of Q1a. Its purpose was to evaluate if, following the workshop, the approach towards the idea of interdisciplinary collaboration has changed. These pair of similar questions employ a retrospective pre-post-methodology [18]. In the rest of Q2, nine Likertscale [19,20] statement-rating questions (range: strongly disagree (1) to strongly agree (5)) were presented, concerning various aspects of the workshop experience. Essentially, the statements considered the effect the workshop had on the perception of interdisciplinary collaboration. We shall hereby list some of these statements:

Q2a - As mentioned above, this was a repeating question, similar to Q1a, for comparing with the pre-workshop response.

Q2b - The workshopprovided tools forinterdisciplinary co-working with colleagues from the other faculties.

Q2c - The workshopcontributed to the creation of meaningfulinterdisciplinary co-working relationships.

Q3 – The students who participated in the program completed a final form. This questionnaire examined their views in retrospect, with the purpose of evaluating the long-termimpact of the program. Here again, in the form ofLikert scale statement-rating questions. The statements were as follows:

Q3a - The experience of participating in the workshop was positive.

Q3b - I maintained contact with the students from other faculties, whom I met at the workshop.

Q3c - I maintained contact with students from other departments of my faculty whom I met at the workshop.

Q3d - The workshop positively affected my interest in participating in a joint project (e.g. a final project), with students from another faculty.

Q3e - The workshop positively affected my interest in doing a joint project (e.g. a final project), with students from another department at my faculty.

Q3f - During the workshop, I learned to do things that, although they belong to other fields, can contribute me professionally.

Q3g - At the workshop, I acquired tools, or way of thinking, in the field of entrepreneurship.

Q3h - Following the workshop, I do or did a joint project with students from another department at my faculty. In case the answer is “no”, indicate the main reason from the list below:

(a) I was not offered a subject for a multidisciplinary project within my Faculty;

(b) I have no interest in implementing a multidisciplinary project within the Faculty. I prefer to carry out a "good" project in my own field only;

(c) I was offered a subject for an interdisciplinary project within the Faculty, but it seemed that the component in my specific field was not interesting enough;

(d) There was no significant connection maintained between me and students from other departments of my faculty, from which an interesting interdisciplinary project might evolve;

(e) The relevant industry (where I am supposed to work at the end of my studies), does not consider an interdisciplinary as one that provides any advantage. Perhaps, in fact, the opposite is true;

(f) being involved in an interdisciplinary project "complicates life", and I am just interested in finishing my studies soon and get a job;

(g) Other reason.

Q3i -Following the workshop, I was involved in a joint project with students from the other faculty. In case the answer is “no”, indicate the main reason from the list belowfrom the list given for Q3h.

IV. RESULTS

The study reported in the paper refers to *Merkaha* 6 (i.e. the 6^{th} time that this annual event took place, March 2018). The results are given with respect to each of the three questionnaires. Each questionnairere presents a different stage of the study and examined at a different time. The first questionnaire relates to the initial perception of the students, with respect to the concept of interdisciplinary collaboration. The second questionnaire immediately followed the workshop. It considered the workshop content, and the effect it had on the initial perception of the participating students. The third questionnaire examined the implications of the workshops on the students, a year later.

Most of the questions were presented in the form of Likert scale statement-rating questions (range: strongly disagree (1) to strongly agree (5)). We chose to present the results of these statements via a weighted average grade (WAG), calculated as follows:

$$WAG = \frac{N_1+2N_2+3N_3+4N_4+5N_5}{\sum N_i} \quad (1)$$

Where i is the statement rating assigned by the responder (from 1 to 5), and N_i is the respective number of answers. The higher the grade, the more the student crowd agrees with the respective statement. WAG=2.5 may be considered a neutral answer. We calculated separately for the engineering (WAG_{eng}) and design (WAG_{design}) students.

Q1 – recall that this questionnaire was answered prior to *Merkaha*.

Q1a-66% of the students affirmed that there is a need for an interdisciplinary collaboration.As arguments, they indicatedthe importance of mutual understanding, the possibility of opening up to different ways of thinking, and creativity that can be enhanced through interdisciplinary interaction. A typical answer that summarizes these: "Collaboration broadens horizons and general knowledge and makes us learn new methods of work”. 34% reported that they were not sure of the need for interdisciplinary collaboration between designers and engineers sums. A typical summarizing answer on this side: “a person would better focus and excel in his own profession, e.g. be a good engineer, rather than worry about ways to collaborate with other disciplines". WAG_{eng}=3.32, WAG_{design}=3.28.

Q2– recall that this questionnairewas more detailed, referring to the actual workshop experience, and consisted of seven statements.

Q2a - This time, 88% of the students (vs. 66%, for the similar Q1a) responded positively. The high percentage indicates that 1) this positive perception is widely accepted and 2) the workshop was effective in enhancing this earlier positive perception. We than followed with an analysis of the answers to the open question "Why?" The answers were referring to three types of benefit attributed the workshop: professional (44% of the answers), social (9%) and personal (47%). Perhaps most relevant to this study are those answers that referred to the professional benefit. A representative answer from an engineering student summarizes this way of thinking: "In the real world, after graduation, no engineer works alone and will normally collaborate with other professionals, many of which would come from a different discipline. All parties involved will have to understand the impact of the other’s work on them, and on the project (even if it is only a relatively simple mechanism). Thus, early collaborations (as in the workshop) are useful for understanding the background from which engineers and designers arrive and to prepare the ground for better functioning of future engineers." WAG_{eng}=4.41, WAGdesign=4.30.

Q2b - 36% of the students responded positively that the tools they received at the workshop contributed to the completion of the project, while 36% responded that the tools they received did not contribute. WAGeng=1.90, WAG_{design}=1.75.

Q2c - 53% of the students responded positively, whereas24% responded that the workshop constraints made it difficult for them to establish meaningful interdisciplinary co-working relationships. The constraints referred to are limited timeframe, tool availability and workspace. Note that some of the workshops demanded the design and preparation of complex projects such as tools for people with disabilities. WAG_{eng}=2.81, WAG_{design}=2.51.

Q3– recall that this questionnairewas referring to the longer term (one year) effect of the workshop. The number of responders was considerably smaller than in Q1 & Q2, possibly due to the long time that passed since the workshop.

Q3a – 33% of the students agreed to this statement (that the workshop experience was positive), and 42% did not. WAG_{eng}=1.82, WAG_{design}=1.45.

Q3b - Only 4% of the studentswho met during the workshop-maintained contact after one year with the students from the other faculty, WAG_{eng}=0.22, WAG_{design}=0.18.

Q3c - only 16% of the students who met during the workshop-maintained contact with students from other departments at the same faculty. WAG_{eng}=0.84, WAG design=0.72.

Q3d - 54% of the students declared that they would like to carry out a follow-up joint interdisciplinary project, with students of the other faculty. WAG_{eng} = 3.05, WAG_{design}=2.57.

Q3e - 66% of the students agreed that they would like to carry out a follow-up joint project, together with students with students from another department of their own faculty. WAG_{eng}=3.58, WAG_{design}=2.68.

Q3f - 63% of the students agreed with the statement (that the learned to do things from the "other" field that would be useful for them professionally). We asked students to provide examples. Here are few: planning a project at all its various stages, dealing with computer programming at a deeper level, dealing with electronic prototyping tools (such as Arduino).WAG_{eng}=3.55, WAG_{design}=2.76.

Q3g - 71% of the students responded that this first experience in a Hackathon-like workshop helped them understand the entrepreneurial world better. Among the examples that the students gave for the respective benefits were:I learned to present topics to an audience, experienced interdisciplinary thinking, having to deal with preparing and organizing things that they had never learned before, met inspiring mentors who are entrepreneurs themselves, work more independently, coped with tight constraints such as time,teamwork and different ways of thinking. WAG_{eng}=4.42, WAG_{design}=3.13.

Q3h - 14% of the students responded positively (i.e. that they had carried interdisciplinary projects with students from another department in their own faculty), 86% gave a negative answer. The distribution of the main reason is given in table 1:

Table 1 Main reasons for the lack of implementation of interdisciplinary projects with students from another department

a	I was not offered a subject for a multidisciplinary project within the Faculty	27.3%
b	I have no interest in implementing a multidisciplinary project within the Faculty. I prefer to carry out a "good" project in my own field only	13.6%
c	I was offered a subject for an interdisciplinary project within the Faculty, but it seemed that the component in my specific field was not interesting enough	1.5%
d	There was no significant connection maintained between me and students from other departments of my faculty, from which an interesting interdisciplinary project might evolve.	39.4%
e	The relevant industry (where I am supposed to work after graduation), does not consider an interdisciplinary as one that provides any advantage. Perhaps, in fact, the opposite is true.	1.5%
f	Being involved in an interdisciplinary project "complicates life", and I am just interested in finishing my studies soon and get a job	4.5%
g	Other reasons	12.2%

Among the other reasons indicated were the difficulty in finding a suitable facilitator for a multidisciplinary project, the great difficulty in scheduling times for co-working, limitations of location, workspace and tools.

Q3i - 6% of the students responded positively (i.e. that they were working on interdisciplinary joint projects with student(s) from another faculty).The vast majority were not involved in such project. The main reasons are indicated in Table 2:

Table 2 Main reasons for the lack of implementation of interdisciplinary projects with students from another faculty

a	I was not offered a subject for an interdisciplinary project combining design or art with engineering	29%
b	I have no interest in implementing a interdisciplinary project within the Faculty. I prefer to carry out a "good" project in my own field only;	14.5%
c	I was offered a subject for an interdisciplinary project within the Faculty, but it seemed that the component in my specific field was not interesting enough.	0%
d	There was no significant connection maintained between me and students from other departments of my faculty, from which an interesting interdisciplinary project might evolve.	36.2%
e	The relevant industry (where I am supposed to work after graduation), does not consider an interdisciplinary as one that provides any advantage. Perhaps, in fact, the opposite is true.	1.4%
f	Being involved in an interdisciplinary project "complicates life", and I am just interested in finishing my studies soon and get a job	1.4%
g	Other reason	12.2%

Among the other reasons indicated in this case were that any attempt to raise a joint project was very unsuccessful, mainly due to lack of willingness to put an extra-effort required for such relatively complex projects to succeed. Some of the students noted that the college did not provide suitable working conditions for students who wanted to work in interdisciplinary projects and some of the students noted that it is very difficult to work together when the time constraints are restrictive and on the other hand, the (disciplinary) demands are high in both faculties.

DISCUSSION

The above results indicate that engineering students, particularly at their early years of study (mid 2nd year in our case), are keen to extend their learning subjects into the interdisciplinary domain. Interestingly, they seem to be somewhat more interested than design students are (judging by the respective higher WAG values). Furthermore, this preliminary interest can be enhanced by exposing the students to the way interdisciplinary collaboration works, e.g. via a Hackathon-like event, such as *Merkaha*. Such experience would typically be enjoyable and leave some good memories.

However, to maintain this level of interest, and develop it into a meaningful element of the engineering studies, a follow-up curricular effort is required. In the absence of such effort, the longer term (in our case, a year after) effect somehow dissolves with time. In the later years of their study, particularly as they approach graduation, students tend to focus on the disciplinary, more specific, subjects of their studies, rather than follow the preliminary interdisciplinary interest, and develop skills in the interdisciplinary domain (most effectively, probably, via a collaborative project).

So, it is clear that one needs to develop and offer a sustaining, relevant, follow-up curricular path for the later years of study. Such curriculum would include suitable courses, and focus on implementing interdisciplinary elements in the final project. Consequently, we, at the EE department, have developed, and implement, an extended curricular program, that consists of four phases:

1. Formative experience event (mid 2nd year) – *Merkaha* (see app. A). This event forms the basic approach students shall have towards the idea of interdisciplinary collaboration, as part of the engineering education.
2. Collaborative inter-departmental courses (during the 3rd year) – at our department, we offer two such courses:
   a. Technological product design course, for EE students(i.e. other engineering or design students are not participating), one semester long (see app. B). The course is mandatory. It starts with ideation and goes through the various phases of entrepreneurship and product design, up to presenting a working prototype.
   b. Lighting design course, for EE and architecture students, one semester long (see app. C). This is an elective course. It goes through the various phases of lighting design and engineering of a given site.
3. Collaborative final project (during the 4th year) –that its end-point is a working, well-designed product prototype. This needs a collaboration between engineering and design students. This is yet a non-standard type of project, and only few students chose this collaborative path so far.
4. Prototyping workshop course – (typically taken at the end of 4th year, or following graduation) – a workshop course, one semester long, titled Prototype2Product. The course is aimed to take the preliminary prototype closer to the market.Ittakes the best prototypes created in phase 3 and advance them into a well-designed product.

CONCLUSIONS

The experience accumulated with *Merkaha* at Shenkar is of about five years. The event is mature enough to provide some indicative data, concerning the proper way to integrate interdisciplinary elements into engineering education. We have carried out such study and reported the main points above.

Essentially, the main conclusions are as follows:

1. Engineering students are keen about the possibility to extend their learning subjects into the interdisciplinary domain.
2. A formative workshop experience, such as *Merkaha*, at an early stage of their studies (typically 2nd year), seems to further enhance the participant's interest in engaging in collaborative, interdisciplinary work. But...
3. …longer term, this motivation typically fades with passing time – in the absence of a suitable follow-up curricular framework. As students approach graduation, they tend to focus on their disciplinary studies, rather than follow their preliminary interdisciplinary interest.

We have proposed above a four-phase curricular framework to sustain this interdisciplinary momentum, and hopefully to educate broader-minded engineers. The program is now in progress. We hope to report some results in due time.

Abbreviations

DT - design thinking

WAG - weighted average grade

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Appendix A – *Merkaha* (Jam) workshops

Merkaha is an annual 3-4 days event, happening in Shenkar since 2012. It takes place during the middle of the 2nd year of study and is mandatory for all 2nd year students at Shenkar College. The study reported here refers to *Merkaha* 6 (i.e. the 6th time that this event took place, in 2018, with ~700 students participating).

Altogether, the event consisted of 45 workshops, each with 16 students participating. Within each workshop, the students worked in heterogeneous groups (i.e. from different departments), typically four students each. Each group were given a challenge within the workshoptheme andfollowed a list of tasks and product requirements. Each product had an engineering- and design- aspects. The workshop starts with each group planninga roadmap, i.e. schedules and tasks. Then, the groups were prototyping. Finally, on the last day of the workshop, each group presents their solutions to the other groups in the workshop.

The *Merkaha* framework stimulatesan interdisciplinary dialogue that is almost impossible in the traditional, routineacademic learning process. The mixing of participants with a wide variety of backgrounds reflected reality, but also enabled participants to exchange better experiences and understand different perspectives. This formative experience was designed to provide a unique experience for students and at the same time enabled faculty members from various departments to meet, work together and build interdisciplinary courses that reflect their knowledge and interest. Interdisciplinary pedagogy combines fields of study and engenders a new curriculum that requires lecturers who study, teach and create together in a new space that blurs the boundaries between the disciplines to re-examine their pedagogical tools and develop teamwork skills.

The workshops were grouped into six broad topics: 1) social making, 2) urban making, 3) craft, 4) Imagineering, 5) Tech & Design, 6) entrepreneurship.

Appendix B – *Technological product R&D course*

The purpose of the course is to let EE students experience the main phases in the process of developing a product. It has been given annually, for the past seven years. The course starts with ideation, followed by product characterization, engineering design of the prototype, product designing of the engineered prototype, preparing a marketing poster and presenting the product (in front of external, business oriented, evaluators). In addition, the course includes expert lectures on innovation subjects, such as financing. Two teachers jointly give the course: a lecturer from the EE department (leads the course) and a product designer.

Two examples of posters describing the respective prototypes, from the recent year, are given in fig. 1.

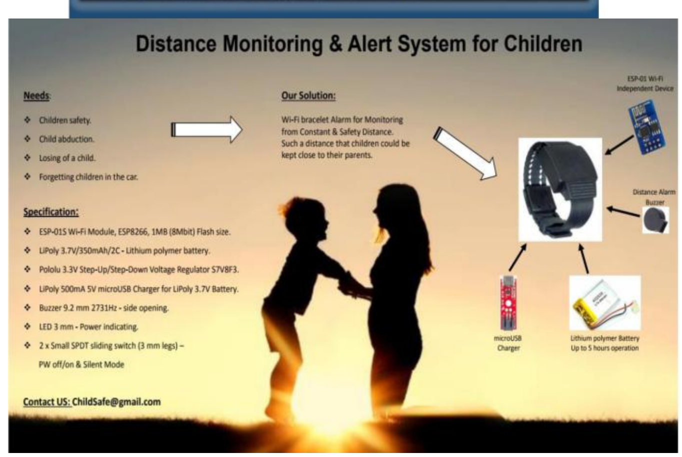

Fig. 1: Two prototype posters developed in the EE course *technological product R&D*, in 2018

Appendix C –*Lighting Design course*

Lighting Design encompasses art, design and science. In general, lighting is everywhere, and has a direct impact on the quality of our lives. As such, this subject matter relates to most students, and provides solid ground for an interdisciplinary learning experience. Although we may sometimes take lighting design for granted (one "just" has to put a suitable lamp in place), it is often a relatively complex task, engineering-wise and design-wise, and one that requires close collaboration. The purpose of the course is thus to let students experience the design process ofa given site lighting, from the perspectives of a designer (typically an architect) and an engineer. The course starts with discussing in depth architectural aspects of lighting a site. This discussion is followed by a quantitative (photometric) lighting analysis and design. The students in class come from two departments: the EE department and the architectural design department. Similarly, two teachers, an architect and an EE lecturer lead the course.