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# The Role of Engineering Design in Technological and 21st Century Competencies Capacity Building: Comparative Case Study in the Middle East, Asia, and Europe

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**Abstract:** Engineering design is considered an effective means for developing engineering technical skills. Normally, engineering design is conducted in teams and is a collaborative open-ended approach under constraints. This nature of engineering design involves engagement of several interpersonal, cognitive, and management skills or competencies such as teamwork, communications, decision making, problem solving, etc. While modern engineers are supposed to be technically competent, they need to posses a wide set of interpersonal, cognitive, and management competencies to function effectively in the workplace. Increasingly there has been more deployment of engineering design competitions (EDCs) in engineering education to address some gaps in current curricula system. In this study, the impact of a complex engineering design competition on developing 21st century competencies of engineering and technology talent is investigated. A mix of quantitative and qualitative methods in the approach to self-reporting perceptions were utilized. Data was collected through interviews from students and faculty, and through surveys from students. Triangulating quantitative and qualitative data from students and faculty indicate that the investigated EDC have positive impact on a large set of 21st century engineering and technology competencies, this has been consistent across groups of students from the EU, Middle East, and Asia, as well as across genders. This is one of the few available investigations that sheds light in further depth on the impact of engineering design on non-technical skills.

**Keywords:** engineering and technology talent; engineering education; design; competencies; knowledge based economy; sustainable development; mixed (quantitative and qualitative) methods

## 1. Introduction

### *1.1. Importance of Engineering Design and Soft Skills in Engineering Education System*

Science and theory oriented engineering curricula that dominated the second half of the 20th century has resulted in graduates far less experienced in engineering practice and design although of understanding complex principals involved in modern technological development and this returns to the focus on theory rather than practical engineering design. One of the increasingly adopted approaches to infuse more practical exposure in the engineering curriculum is capstone design courses, in addition to senior design graduation project taken in the final year.

Furthermore, design in principle is one of the most distinguishing features of the engineering profession, and hence engineering education institutes need to emphasize this as a core pillar in their curriculum. American Accreditation Board for Engineering and Technology (ABET), one of the most influential higher education engineering and technology accrediting bodies, bas been instrumental in pushing focus on design in engineering schools, where design is one of the foundational principles that ABET accreditation. In addition to the limited design competencies development in current science based engineering education system, soft-skills development is also weak [1]. Series of recent studies have emphasized that 21st century engineers should posses a wider set of interpersonal, cognitive, and management competencies [2–4]. On the top of these comes teamwork and communication skills, and several others including but not limited to: ethics, creativity, innovation, leadership, professionalism, etc. [2–4]. Addressing, developing, and measuring soft skills in engineering curriculum has been both scarce and challenge [5]. Engineering curriculum is too technically focused and there is limited space for courses on soft skills development [6], one of the best approaches of developing an all-rounded 21st century engineering talent is to embed existing engineering curriculum and co-curriculum with technical approaches that leads to a wide set of competencies development; design courses, projects, and co-curriculum activities can be a well-suited platform for this embedded approach.

### *1.2. Engineering Design Competitions (EDCs)*

There has been increasing emergence of engineering design competitions on regional or global levels, as well as, more popularity among students to participate in such competitions. Increasingly there has been more deployment of complex design competitions in engineering education to address some gaps in current curricula system. Some of these competitions are: American Society for Mechanical Engineering student design competition; Formula SAE student design competition by Society for Automotive Engineers (SAE) International; Shell-Eco Marathon by Shell; American Helicopter Society students competition; American Solar Challenge by US Department of Energy; Design for Digital Manufacturing by the Society for Manufacturing Engineers; NASA College and University Aeronautic Design Challenges by NASA; University Rover Challenge by Mars Society; and World Solar Challenge by adventurer Hans Tholstrup in Australia.

The automotive EDCs have been in particular popular among engineering students, such as Formula SAE, and Shell Eco-Marathon; see Figure 1. The Formula SAE student competition is organized annually, it aims at students designing a Formula 1 like car on a smaller scale and competing against other students' teams worldwide. The competition has two classes and universities can participate in either or both classes. Class 1 is the main event in which students compete in the cars they have designed and implemented. Judging criteria is categorized around two categories, static and dynamic. In static categories, evaluation is focused engineering and business specifications such engineering designs, cost and sustainability, business presentation, and rigorous technical inspection. In the dynamic category, evaluation is focused on aspects such as autocross, acceleration, and endurance. Class 2 can be considered as a competition for work-in-progress for the teams building cars for Class 1. Here teams are judged on business presentation, cost, and engineering design. Class 2 allows students to refine their skills, get feedback, and improve their design in the process of completing the product for Class 1 event.


**Figure 1.** EDCs cars in race, Formula SAE (**left**) and Shell Eco-Marathon (**right**).

The Shell Eco-Marathon (SEM) design competition aims at designing cars with lowest possible energy consumption. There are two categories of cars based on energy type: 1—cars with internal combustion engine (normally petrol, diesel, liquid fuel made from natural gas and ethanol); and 2—cars with electric engine powered by hydrogen fuel cells and lithium-based batteries. The main judgement criteria is the furthest possible travel on equivalent energy to one liter of fuel. Designed cars by students will normally conduct a fixed number of laps during the event, and the organizers will calculate their energy efficiency and winning teams area announced towards the end of the event. There are also a number of off-track awards for design, teamwork, and safety. The design experience is complex and normally a car is built via a team of 5–10 students from different disciplines, including mechanical, electrical, and sometimes computing and chemical engineering. Normally participants are higher education students, except in the US the focus is on K-12 schools students.

### *1.3. Engineering Education Impact of Engineering Design Competitions (EDCs), and Gaps in the Literature*

In many cases, EDCs have been used as a platform for graduation projects of engineering students in BSc or MSc levels (see for instance [7–9]). In other cases, the complex design experience and competitions were utilized as a framework for integrating engineering learning from freshman to senior years in engineering schools, enhance engineering learning, and/or platform for project based learning [10–13]. Automotive EDCs promote learning and mastery of limitless set of technical and engineering concepts and approaches mastery, such as: computational fluid dynamics, control design, solar engineering, chassis design, combustion, computer aided design and simulation, prototyping, testing, materials engineering, thermodynamics, systems engineering, modelling, fuel efficiency, optimization, aerodynamics, embedded systems, mechanics, manufacturing, numerical analysis, safety engineering, sensing and actuating, computer aided analysis, reliability engineering, etc.; A numerous number of disseminations have been reported on the various design, technical, and engineering learning taking place in design competitions, see for instance list in Appendix A.

Apart from development of core technical engineering competencies, the collaborative, constrained, and inter-/multi-disciplinary nature of engineering design and competitions could lead also to development of several soft skills or competencies [11,13]; however, there is very limited reports of in-depth research on the impact on non-technical skills development. The research reported in this paper measured, among others, the impact of an automotive EDC on engineering competencies using a four-dimensional model of the 21st century skills of modern engineering and technology talent [14,15].

## **2. A Four Dimensional Model of Twenty First Century Engineering Competencies**

Engineers are normally associated with technical competencies, however emphasize of needs of engineers to posses several other non-technical competencies can be traced in the literature for couple of previous decades. Significant number of literature have been published on this topic in developed countries and emerging economies such as USA [16–18], Australia [19–21], UK [22–24], Canada [25], etc. Comprehensive study on talent needed for 21st century engineers have developed four dimensional model of engineering technical and soft competencies [14,15] in which several competencies are bundled in each dimension. The study scanned over 200 research articles and policy reports in various topics related to engineering skills, employability, 21st century competencies, etc. The developed dimensions are outlined in the next subsections together with their competencies; for more in-depth details on the literature behind each competency, see [15].

### *2.1. Dimension I: Core Engineering Knowledge and Practice*

In this dimension core professional field and general knowledge competencies are bundled, these are: 1—Math, Physics, Science Fundamentals [26–28]; 2—Disciplinary Engineering Fundamentals [29]; 3—Interdisciplinary engineering knowledge [30,31]; 4—Multidisciplinary Knowledge [17,26,27];

5—Practical Skills [22,32,33]; and 6—Information and Communication/Computer Technology Skills [34–36].

### 2.2. Dimension II: Cognition and Thinking

In this dimension competencies associated with cognition and thinking are bundled. These are: 1—Problem Solving Skills [37–39]; 2—Lifelong learning [21,28,40]; 3—Decision Making [29,41–43]; 4—Analytical Thinking; 5—System Thinking [29,44]; 6—Critical Thinking [45]; 7—Creative Thinking, 8—Innovation Skills [35]; and 9—Design [31,41].

### 2.3. Dimension III: Professional and Interpersonal

In this dimension competencies associated with professional and interpersonal behavior and values are bundled. These are: 1—Professionalism [46]; 2—Ethics and Responsibility [17,26,47]; 3—Communication Skills [41,47]; 4—Teamwork Skills [18].

### 2.4. Dimension IV: Business and Management

In this dimension competencies associated with business and management are bundled. These are: 1—Business and Management skills [22]; 2—Leadership Skills [22,42], and 3—Entrepreneurship Skills [26,45].

## 3. Research Questions, Assessment Plan, and Methodologies

Shell eco Marathon complex Design project assessment on students has been conducted towards the end of the contest held in Europe and Asia in year 2014. This assessment has been conducted to investigate the impact of design experience project on student's competencies development.

### 3.1. Research Questions

A number of research questions have been formulated to achieve the study's objective in investigating the impact of the engineering design competition (EDC) of Shell Eco-Marathon on students. The main research questions were:

- What are the main purposes of students' participation in EDC?
- Are there differences in impact of EDC on students from Europe, Asia, and the Middle East?
- What is the impact of EDC experience on 21st century engineering competencies development compared with University formal engineering education impact?

### 3.2. Materials and Methods

The methodology of the assessment included a mixed quantitative and qualitative methods approach, where surveys were administered and interviews were conducted. Comparative quantitative assessment focused on comparing responses among the following groups:

- Middle Eastern
- Asian students
- European students
- Males
- Females

Inferential and descriptive statistics methods were utilized to analyze and report on the quantitative data findings. Interviews were transcribed in full, and analyzed using content analysis to report on findings.

### 3.3. Instruments Administration

Surveys were delivered to European participating students (*n* = 131), Asian students (*n* = 109) and Middle Eastern students (*n* = 33) during the days of the two events (approx. 3 days each), an expert delivered the surveys for students and they answered in his presence to insure clarifying any question emerging from the students. Interviews were conducted by the expert with students and instructors during the two events, a total of around 64 interviews were conducted, raging on average 20 min each, ME (16 students, 5 supervisors), EU (12 students, 9 supervisors), and Asia (16 students, 6 supervisors).

### 3.4. Survey Structure, Reliability, and Validity

The survey included sections on demographics and measures of students' satisfaction with 21st century competencies development by University, and by the design experience in Shell competition. The survey design stemmed from research questions stated earlier and also from exploratory interviews with Qatar University faculty involved in SEM; sample survey is shown in Appendix B. Reliability was demonstrated using Cronbach's alpha which should be above 0.9 to indicate valid reliability (Cronbach and Meehl, 1955). Reliability of the designed survey has been calculated indicated a value of 0.983 > 0.9 representing high internal consistency. Validity is reported through inferential statistics with statistical significance results at the 5% threshold.

## 4. Demographics

The whole students sample number is *n* = 273, in which European students (*n* = 131), Asian students (*n* = 109) and Middle Eastern students (*n* = 33) (Note Middle Eastern countries included are all Arabian countries in addition to Turkey).

Students were of both genders; Males and Females but most of them are Males *n* = 217(80%) while Females *n* = 54 (20%), taking into consideration that Middle Eastern students Males *n* = 28 (85%) while Females *n* = 5 (15%), Asian students Males *n* = 92 (85%) while Females *n* = 17 (15%) and European Males *n* = 97 (75%) and Females *n* = 32 (25%), see Table 1; Most students are of average age of 22. When students were asked about their English proficiency *n* = 105 (38.7%) students stated that they are good in English (MEA *n* = 13 (39.4%), Europe *n* = 50 (38.2%) and Asia *n* = 42 (39.3%).

**Table 1.** Statistics of genders.

| Genders | Origin | | | Total |
|---|---|---|---|---|
| | Europe | Asia | Middle East | |
| Male | 97 (75%) | 92(85%) | 28 (85%) | 217 (80%) |
| Female | 32 (25%) | 17 (15%) | 5 (15%) | 54 (20%) |
| Total | 129 (47.6%) | 109 (40.2%) | 33 (12.2%) | 271 (100%) |

The mechanical engineering major accounted for more than half of the student population *n* = (152) (56%) (MEA *n* = 19 (57.5%), Asia *n* = 59 (54.1%), and Europe *n* = 74 (56.9%)) followed by other majors (e.g., mechatronics, automotive, and control systems) *n* = 45 (17%), then finally followed by electrical engineering *n* = (28) (10%) (MEA *n* = 3 (9%), Europe *n* = 13 (10%) and Asia *n* = 12 (11%)). Also most of the students were seniors *n* = (141) (53%) (MEA *n* = 16 (50%), Europe *n* = 52 (41%) and Asia *n* = 73 (68%)) followed by other Juniors *n* = 48 (18%) in which MEA *n* = 6 (18%), European *n* = 26 (20%) and Asians *n* = 16 (15%) and finally graduate students *n* = 32(12%) in which MEA *n* = 2 (6%), European *n* = 27 (20%) and Asians *n* = 3 (3%).

## 5. Quantitative Data Analysis

### *5.1. Purpose of Participation and Previous Engineering Experience*

Students were asked about the purpose behind which they joined EDC in which most of the students $n$ = 165 (63%) stated that EDC is an extra-curriculum activity (voluntary with no credit hours) (MEA $n$ = 26 (78.8%), Europe $n$ = 75 (60%) and Asia $n$ = 64 (62.75%)) followed by being a senior (graduation) project $n$ = 39 (15%) (MEA $n$ = 7(21.2%), Europe $n$ = 18(14.4%) and Asia $n$ = 4 (13.7%)); see Table 2.

**Table 2.** Joining EDC purpose.

| Purpose of Participation | Origin | | | Total |
|---|---|---|---|---|
| | Europe | Asia | Middle East | |
| extra-curriculum activity (voluntary with no credit hours) | 75 (60%) | 64 (62.75%) | 26 (78.8%) | 165 (63%) |
| senior (graduation) project | 18 (14.4%) | 14 (13.7%) | 7 (21.2%) | 39 (15%) |
| Others | 32 (25.6%) | 24 (23.55%) | 0 (0%) | 56 (22%) |

In addition, students were asked to define the incentives of their participation in EDC project and rank the top 3 of them. Middle eastern and Asians students opinions are the same as most of them pointed to enhancement of their engineering skills $n$ = 28 (85%), $n$ = 95 (87%) respectively ranked as 1 followed by rank 2 of finding it interesting $n$ = 27 (82%) and $n$ = 88 (81%) respectively while European students had different opinion as most of them ranked finding it interesting as 1 ($n$ = 115) (89%) followed by enhancement of their engineering skills ($n$ = 99) (75.5%); while rank 3 for both EU and ME was the same "travel experience" (EU $n$ = 63 (48.5%), Asians $n$ = 17 (51.5%)) but Asians ranked "wining the competition" as 3 with sample no. $n$ = 53 (48.6%); see Table 3.

**Table 3.** Ranking of Shell Eco Marathon incentives.

| Rank | Origin | | |
|---|---|---|---|
| | Europe | Asia | Middle East |
| **Rank 1** | Finding it interesting $n$ = 115 (89%) | Enhancement of engineering skills $n$ = 95 (87%) | Enhancement of engineering skills $n$ = 28 (85%) |
| **Rank 2** | Enhancement of engineering skills $n$ = 99 (75.5%) | Finding it interesting $n$ = 88 (81%) | Finding it interesting $n$ = 27 (82%) |
| **Rank 3** | Travel experience $n$ = 63 (48.5%) | Wining the competition $n$ = 53 (48.6%) | Travel Experience $n$ = 17 (51.5%) |

### *5.2. EDC Impact on Development of Twenty First Century Competencies of Engineering Graduates*

Students were asked to evaluate themselves on how much they are satisfied with the contribution of both their university study and EDC experience to the development of a set of 23 competencies. These competencies are expected to represent the needs of 21st century engineering graduates, and are grouped under four main dimensions: 1—"core engineering knowledge and practice"; 2—"cognition and thinking"; 3—"professional and interpersonal"; and 4—"management and business". The following question was stated in the survey:

> *"To which extent do you Agree or Disagree that University Study and Shell Eco Marathon Competition contributes to the development of the following skills tabulated below."*

Students needed to rate their response on a Likert scale from 1 to 5, where: "1 = Strongly Disagree (SD)"; "2 = Disagree (D)"; "3 = Neutral"; "4 = Agree (A)"; "5 = Strongly Agree (SA)".

Below are reports of the assessment based on the comparison between Asian, Europeans and Middle Eastern, as well as Male and Female students.

#### 5.2.1. EDC Comparative Impact on Investigated Groups: Asian, EU, ME, Male, and Female

EDC and 21st Century Engineering Competencies—Asian vs. EU

Generally both EU and Asian students were positive in regards with impact of EDC experience on all 23 surveyed competencies (average score around 4 = "Agree"). Overall, Asian students have reported higher means than EU students of EDC impact on 21 out of the 23 surveyed competencies, with 13 of these 21 competencies have statistically significant higher mean as revealed by inferential statistics using Mann Whitney U test. Table 4 shows statistics of the analysis of the "Dimension II Cognition, thinking, and mental", Table A2 through Table A4 in Appendix C shows rest of results.

**Table 4.** Dimension II Cognition thinking and mental. European and Asian Students engineering perceptual scores of EDC post participation on 21st Century skills.

| Variable | Mean | | Sample Number | *p*-Value (Mann Whitney) | Statistical Significance |
|---|---|---|---|---|---|
| Lifelong Learning | European<br>Asian | 3.86<br>4.21 | 123<br>100 | 0.006 | Yes |
| Problem Solving | European<br>Asian | 4.21<br>4.17 | 125<br>100 | 0.632 | No |
| Decision Making | European<br>Asian | 3.98<br>4.23 | 123<br>101 | 0.099 | No |
| Analytical Thinking | European<br>Asian | 3.98<br>4.34 | 125<br>101 | 0.002 | Yes |
| Systems Thinking | European<br>Asian | 3.90<br>4.27 | 125<br>101 | 0.002 | Yes |
| Critical Thinking | European<br>Asian | 3.94<br>4.24 | 125<br>101 | 0.023 | Yes |
| Creative Thinking | European<br>Asian | 4.15<br>4.25 | 125<br>101 | 0.520 | No |
| Innovation | European<br>Asian | 3.97<br>4.26 | 125<br>101 | 0.032 | Yes |
| Design | European<br>Asian | 3.97<br>4.16 | 125<br>101 | 0.138 | No |

EDC and 21st Century Engineering Competencies—ME vs. EU

Generally both ME and EU students were positive in regards with impact of EDC experience on all 23 surveyed competencies (average score around 4 = "Agree"). Overall, ME students have reported higher means than EU students of EDC impact on all of the 23 surveyed competencies, with 12 of these 23 competencies have statistically significant higher mean as revealed by inferential statistics using Mann Whitney U test [48]; Table 5 shows statistics of the analysis of the "Dimension III Professional and interpersonal", Table A5 through Table A7 in Appendix C shows rest of results.

**Table 5.** Dimension III: Professional and interpersonal. Middle eastern and European Students engineering perceptual scores of EDC post-participation on 21st century skills.

| Variable | Mean | | Sample Number | *p*-Value (Mann Whitney) | Statistical Significance |
|---|---|---|---|---|---|
| Professionalism | Middle eastern<br>European | 4.31<br>3.94 | 29<br>124 | 0.012 | Yes |
| Ethics and Responsibility | Middle eastern<br>European | 4.31<br>3.72 | 29<br>124 | 0.002 | Yes |
| Adaptability | Middle eastern<br>European | 4.14<br>4.09 | 29<br>123 | 0.618 | No |
| Communication | Middle eastern<br>European | 4.46<br>3.89 | 28<br>123 | 0.002 | Yes |
| Teamwork | Middle eastern<br>European | 4.52<br>4.33 | 29<br>123 | 0.185 | No |

EDC and 21st Century Engineering Competencies—ME vs. Asian

Generally both ME and Asian students were positive in regards with impact of EDC experience on all 23 surveyed competencies (average score around 4 = "Agree"). Means were comparable for both groups with no statistically significant difference in 21 competencies out of the surveyed 23 competencies. ME students scored statistically significant higher in two competencies as revealed by inferential statistics using Mann Whitney U test: "Design" and "Management".

EDC and 21st Century Engineering Competencies—Males vs. Females

Generally both Male and Female students were positive in regards with impact of EDC experience on all 23 surveyed competencies (average score around 4 = "Agree"). Means were comparable for both groups with no statistically significant difference in 22 competencies out of the surveyed 23 competencies. Male students scored statistically significant higher in only in one competency: "Leadership" as revealed by inferential statistics using Mann Whitney U test, maybe this is due that male students were given a leadership opportunity more than females.

#### 5.2.2. Comparative Impact on Skills Development: University vs. EDC

To compare students' responses on their evaluation of competencies development between University and Shell Eco-Marathon, the Wilcoxon test [48] was performed together with descriptive of means of answers. Overall all groups of students Asian, EU, ME, Male, and Female have reported higher means in favor of EDC in all assessed skills. Wilcoxon test revealed statistically significant difference in most skills (with exception of "Math, Physics, & Science Fundamentals" in which most groups did not score statistical significance; ME students did not score statistically significant in "ICT skills", "Life Long Learning", and "Analytical Thinking"). This indicates that students at scale percept EDC design experience as a better vehicle for skills development than a university, see Table 6 below for sample of the responses; full statistics are in Table A8 through Table A10 in Appendix D.

**Table 6.** Dimension I: Core Engineering knowledge and practice. Wilcoxon Test (in-group EDC vs. University) and Perceptual gap of 21st century skills 1st dimension between European, Asians and Middle Eastern as well as genders comparing university studies and post EDC participation.

| Variable | Group under Study | Perceptual Gap/Wilcoxon | Gender | Perceptual Gap/Wilcoxon |
|---|---|---|---|---|
| Disciplinarily Engineering Fundamentals (Depth) | European<br>Asian<br>Middle eastern | 0.69/0.000<br>0.66/0.000<br>0.72/0.001 | Male<br>Female | 0.71/0.000<br>0.64/0.003 |
| Interdisciplinary Engineering Knowledge (Breadth) | European<br>Asian<br>Middle eastern | 0.76/0.000<br>0.75/0.000<br>0.71/0.001 | Male<br>Female | 0.76/0.000<br>0.71/0.000 |
| Math, Physics, and Science Fundamentals | European<br>Asian<br>Middle eastern | 0.10/0.522<br>0.47/0.000<br>0.10/0.983 | Male<br>Female | 0.18/0.121<br>0.06/0.972 |
| Practical Experience | European<br>Asian<br>Middle eastern | 1.42/0.000<br>0.87/0.000<br>1.12/0.000 | Male<br>Female | 1.17/0.000<br>1.21/0.000 |
| ICT Experience | European<br>Asian<br>Middle eastern | 0.57/0.000<br>0.49/0.000<br>0.43/0.076 | Male<br>Female | 0.45/0.000<br>0.77/0.000 |
| Multidisciplinary Knowledge | European<br>Asian<br>Middle eastern | 0.65/0.000<br>0.61/0.000<br>0.82/0.001 | Male<br>Female | 0.68/0.000<br>0.57/0.001 |

#### 5.2.3. Twenty First Century skills Perceptual Gap: University vs. EDC Experience

Gap analysis was carried out in order to know if there is perceptual gap in the perceptions/satisfaction of students' of EDC experience vs. University experience in developing twenty first century engineering competencies. In order to quantify perceptual gap (EDC vs. Uni), the mean of satisfaction level of University experience was subtracted from the mean of the satisfaction level of EDC experience.

The Mann Whitney U test was used to determine the significance of perceptual gap of the 21st Century skills. No statistically significance difference was revealed between all of the 5 groups under study except in few cases related to Asians and EU, and males and females. Five skills out of the 23 skills showed statistical significance between Asians and EUs in which Asians showed higher means, these are: "Math, Physics, and Science Fundamentals", "Analytical Thinking", "Systems Thinking", "Ethics and Responsibility", and "Entrepreneurship". EU students showed statistically significant higher perceptual gap only for "Practical skills" with Asian students. Two skills showed statistical significance between Males and Females in which males showed higher means, these are "Critical thinking" and "System thinking".

Table 6 shows for sample of the perceptual gaps; full statistics are in Table A8 through Table A10 in Appendix D; highlights in yellow indicated top differences. The highest perceptual gap (EDC vs. University) of the European students was mainly in the following competencies (% refers to the percentage of gap difference between EDC satisfaction and University satisfaction):

- Practical experience (1.42) (28.4%).
- Teamwork (0.97) (19.4%).
- Creative thinking (0.87) (17.4%).
- Decision making (0.80) (16%)
- Problem solving (0.76) (15.2%).

The highest perceptual gap (EDC vs. University) of the Middle Eastern students was mainly in the following competencies:

- Practical experience (1.12) (22.4%).
- Teamwork (1.02) (20.4%).
- Decision making (0.91) (18.2%).
- Management (0.89) (17.8%).
- Professionalism (0.88) (17.6%).

The highest perceptual gap (EDC vs. University) of the Asian students was mainly in the following competencies:

- Practical experience (0.87) (17.4%).
- Teamwork (0.81) (16.2%).
- Creative Thinking (0.79) (15.8%).
- Analytical thinking (0.78) (15.6%).
- Systems thinking (0.78) (15.6%).

The highest perceptual gap (EDC vs. University) of the Male students was mainly in the following competencies:

- Practical experience (1.17) (23.4%).
- Teamwork (0.95) (19%).
- Creative Thinking (0.86) (17.2%).
- Decision making (0.80) (16%)
- Leadership (0.76) (15.2%).

The highest perceptual gap (EDC vs. University) of the Female students was mainly in the following competencies:

- Practical experience (1.21) (24.2%).
- Teamwork (0.77) (15.4%).
- ICT experience (0.77) (15.4%).
- Interdisciplinary Engineering Knowledge (Breadth) (0.71) (14.2%).
- Multidisciplinary knowledge (0.68) (13.6%).

From the gaps above, impact of EDC on competencies development as compared with University is highest at practical skills and teamwork (appearing among top list for all groups), followed by decision making and creative thinking (appearing in 3–4 groups top list). This may indicate that engineering education system in EU, ME, and Asia is still heavily relying on theory and solo-student study approach, where limited practical/hands-on curricular opportunities are given and low push for social and team-work study approaches. ICT only appeared with the female group, this may indicate gender preference for ICT skills learning through practical complex application. The gender difference in developmental impact between males and females shows also in the three competencies after practical experience and teamwork. Males seems to develop more of cognitive and leadership in the investigated EDC, while females tend to develop more of the core competency dimension. Understanding why these differences occurs between genders may require more in-depth investigation and analysis.

## 6. Qualitative Data Analysis Findings

### *6.1. Motivation of Participating in EDC*

Majority of students participated in EDC as a voluntary activity, while a proportion of students participated as part of coursework (sometimes mandatory). Analysis of interviewees have revealed that main motive behind taking part in SME was to gain experience and apply theoretical knowledge into a real context. Students wanted to get some sort of an experience, whether a practical, a technical or a management experience; *"I participated because I feel like it'll give a very good experience in terms of technical and also in terms of management."—Asian student reported.*

### *6.2. Impact on 21st Century Engineering Skills*

Students and faculty were asked in the interviews what kind of skills the students may have gained through partition in EDC and their perception on the development of these skills as when compared to University. In the subsection below we report on analysis findings of transcripts of these interviews. For each of the dimensions we report on 2–3 representative competencies, report is limited to avoid lengthy details of qualitative data and analysis.

#### 6.2.1. Dimension 1: Core Knowledge and Practice

*Math, Physics, and Science Fundamentals*: Students reported that they have to re-call and apply some of their previous knowledge in math and physics. Overall, students do not feel that EDC has a major contribution to their theoretical understanding of math and physics fundamentals as compared to University contributions.

*Interdisciplinary Engineering Knowledge*: Most of the students reported that EDC equipped them with interdisciplinary engineering skills as they have to work with students from other departments and share knowledge with each other based on what discipline they are in. The most reported disciplines that have to work together on EDC were the electrical and mechanical engineering; *"I am computer engineering student, the project itself is mechanical so sometimes I need the help of mechanical on this so we share knowledge and learn little bit of each other."—Asian Student reported.* In general, students reported higher level of developing interdisciplinary knowledge through EDC than through a normal engineering curricula in a University setting, for Instance reported: *"Both but it is more with shell eco-marathon."—EU Student.* Majority of instructors believe that EDC had contributed to the development of interdisciplinary skills more than university because of the interdisciplinary nature of the project itself especially for both Electrical and Mechanical departments. Instructors believed that EDC not only developed such skills for students but also for themselves as academic staff; below are some reports from Instructors: *"Yes or myself I think I learned a lot from the mechanical technical aspects."—Asian Supervisor reported.*

*Practical Skills*: Practical experience skills development was the most frequently reported competency to be developed with EDC among interviewed students and faculty. As a result of participation in EDC, students developed and applied several practical and hands on skills and activities such as drilling, cutting, wiring, programming, CAD design, etc. For instance, below are some reports of students on what kind of practical skills they have developed; *"I think it is a good project overall to apply all the principles we have learned in university on a practical project."—ME Student reported.* The majority of students reported that they did not have any significant practical or design experience in their university, apart from some of the work they do in labs. They reported that practical skills developed through EDC are significantly more than was developed through conventional engineering curricula in the University. Also the majority of instructors believed that students have indeed gained practical experience as a result of participation in EDC; *"It is the most real project students can work on that is close to real industrial projects."—EU Supervisor reported.*

#### 6.2.2. Dimension 2: Impact on Mental, Cognitive, and Affective Skills

*Problem Solving*: Development or enhancement of problem solving skills have been frequently reported by the interviewees. Since EDC is a complex design experience, most students faced high number of new problems in every stage of the design and development and majority of these problems were confronted for the first time. Students have to deal with problem solving in efficient manner in order to be able to progress with their designs and development; *"I think we faced many new problems that we never knew that existed. In theory it is barely mentioned."—ME Student reported.* Students have reported two aspects that pushed them to develop enhanced problem solving skills throughout the EDC: 1—Time limitations/constraints; and 2—The complexity of the project. Most of instructors believed that students have developed higher order of problem solving skills in EDC as compared with conventional engineering curricula in Universities. Instructors related the development of such skill in EDC to the nature of complex design experience where the students were faced with so many problems and tried to come up with different solutions; *"Students who participated in SEM differ from other students in terms of that they are more willing, capable and eager to solve problems as well to serve the community"—ME Supervisor reported.*

*Decision Making*: Decision making skill development has been frequently reported (more than 55 times) by the interviewees. Students make decisions every day in their lives, but it is not as intensive as in EDC. This can be justified by referring to the fact that to produce a final product in EDC, students must make decisions throughout the entire process, whether they are technical decisions such as deciding on which materials and techniques to use, or personal decisions such as how they should be spending their times and what plan should they follow, all of which affect the final product; *"You have to decide about everything even simple things (e.g., materials to use) so there is continuous decision making requirements".—EU Student reported.* Instructors also highlighted the contributions of EDC to development of decision making skills among students. Majority of instructors justified EDC contribution to the development of decision making to the complex nature of this design project. They reported that EDC students can actually observe the consequences of their decisions leading them to develop strategies and competencies of also selecting a best decision; *"They have to solve some difficult problems and take decisions very fast and think."—EU Supervisor reported.*

*Life-Long Learning (LLL) Skills*: Qualitative interviews revealed significant impact of EDC on students' ability of to learn on their own, search for information and teach themselves. The nature of the EDC and its complexity forces students to deal with so many issues by themselves, to search, to learn and be self-learners; *"We searched the internet, we went to experienced people the one that have* *experience in the field, to our Drs. Wherever we can find information we went and looked for it."—MENA Student reported.* Majority of instructors agreed that students have developed significant life-long learning skills as a result of participation in EDC compared to conventional University education. One instructor explains that unlike university courses where students are told what to study and where from, students have to seek knowledge and work had in order to understand the practical work they are doing; *"Of course shell eco-marathon. I don't know about other projects but from my experience in university, students are told to study from here to here but in this event, for application you have to think in order to realize things."—EU Supervisor reported.*

#### 6.2.3. Dimension 3: Impact on Professional and Interpersonal Skills

*Professionalism*: The majority of students and instructors stressed the role of EDC in developing professionalism. In particular, the practical experience nature of EDC was highlighted as a differentiating factor for developing professionalism as when compared with University experience. Students reported professionalism development in EDC due the fact they have to deal with external companies and sponsors in an international experience with people from all over the world. Also dealing with teammates and other teams in a friendly welcoming way is a way to be professional; *"Yes we used to go to meet the marketing managers and different people that they are used to be; We must have professionalism".—Asian student reported.* Some students attributes significant professionalism development in EDC experience as compared to University due to the more authentic/real-world nature of EDC; *"Shell—It is a professional working area, it is more like in the real world environment". ME Student reported.*

*Teamwork Skills*: The majority of students highlighted the significant role of EDC experience in developing teamwork skills as compared with University, this was attributed in many cases to the collaborative design and practical nature of EDC; *"I gained a lot of real life skills like project and team work skills that I can use afterward". EU Student reported.* Majority of supervisors have agreed that the students developed team working skills more in EDC than they ever did in their university studies.

*Communication Skills*: The contribution of EDC in developing or enhancing oral and written communications skills has been one of the most reported competencies by students. Most of the students expressed that they developed higher level of communication skills in EDC experience as compared to the conventional University experiences. Students acquired significant social and communication skills by dealing with professors, with sponsors, and with shell organizers; *"Because it has been a lot of intra-team communication, also contact with possible sponsors and organization at the beginning".—EU Student reported.* Majority of instructors also referred to EDC experience as a significant contributor to development of communications skills as compared with University experiences. Students needed to develop writing skills as several reports and interim written communications needed between team members each other as well as with supervisors, technicians, and sponsors. Similarly, oral professional communications skills were developed due the intensity of project meetings and interim collaborative tasks.

#### 6.2.4. Dimension 4: Impact on Management and Business Skills Development

*Management Skills*: Overall, majority of students have agreed that they have developed management skills due to participation in EDC more than they did due to their university studies. EDC students managed their work by planning their tasks from the beginning that had a positive impact in work flow, they planned the work process by various ways as preparing charts, setting timelines and setting their goals preparing periodic reports in order to make sure everything is going as planned; *"It taught me how to make a plan, reach my objectives, and organize/manage myself"—EU Student reported.*

*Marketing and Entrepreneurship Skills*: Participating teams in EDC had to find their own funds to cover the required expenses. While the students faced significant difficulties in the process of sponsorship and funding, many succeeded in acquiring funds through several marketing ways, such as contacting different companies, sending emails, approaching them and convincing them that this shall brand their products and logos, etc. Students have reported the development of marketing and presentation skills as a result of sponsorship seeking tasks. Majority of students and instructors believe that contribution of EDC experience to developing entrepreneurship skills is rather minimal as it is not a focus of the competition.

### *6.3. Quantifying of Qualitative Findings*

The interviews have revealed that the complex design experiences in the EDC project have made significant contributions to several competencies and attributes, some technical and quite few are non-technical. In quantifying reports of students, the top ranked frequently reported enhanced competencies compiling both supervisors and students (calculated as sum) responses are: 1—Communications. 2—Management; 3—Teamwork; 4—Inter- and Multi-disciplinary knowledge; 5—Practical Experience; 6—Decision making; see Table 7 for list of top 10 for each of the students and the supervisors.

**Table 7.** List of top 10 frequently reported competencies to be developed by EDC (with their frequency of report).

| **Students (*n* = 44)** | **Supervisors (*n* = 20)** |
|---|---|
| Communications (91 times) | Project Management (47 times) |
| Project Management (77 times) | Inter- and Multi-Disciplinary knowledge (34 times) |
| Teamwork (67 times) | Design skills (31 times) |
| Decision making (58 times) | Communications (29 times) |
| Inter- and Multi- Disciplinary knowledge (58 times) | Teamwork (28 times) |
| Practical experience (57 times) | Practical experience (27 times) |
| Problem solving (47 times) | Problem solving (20 times) |
| ICT (45 times) | Adaptability (19 times) |
| Life Long Learning (44 times) | Creativity (19 times) |
| Creativity (42 times) | Professionalism (19 times) |
| Environmental awareness (41 times) | Leadership (16 times) |

## 7. Summary of Mixed Methods Analysis Main Findings

### *7.1. Quantitative Analysis Main Findings*

Most students (ca. 63%) participated in the competition as an extra curricular activity, and enhancing their engineering skills was among top ranked incentives to join across all groups of EU, Asian, and ME students.

Overall limited differences have been observed between investigated groups: EU, Asian, ME, and Males and Females in terms of EDC impact. EDC is found to have a statistically significant impact on the level of self-perceived development of the vast majority of 21st century engineering skills (total of 23 skills were surveyed) as compared with University contribution to skills development. The statistically significant impact was consistent with all analyzed groups: EU, ME, and Asians, as well as Males and Females.

For the five investigated categories (EU, ME, Asian, and Male and Female students), the top five highlighted skills that EDC had left higher impact on their development than conventional University experience (measured by means of perceptual gap in means) are:

- Practical Experience (reported by five categories, also reported as nr.1. in all categories).
- Teamwork (reported by five categories, also reported as nr.1. in all categories).
- Creative thinking (reported by 3 categories out of five).
- Decision making (reported by 3 categories; also reported as nr.4. in two categories; ME reported as nr.3.).

Problem solving; Professionalism; Analytical thinking; Systems thinking; Leadership; ICT experience; Interdisciplinary engineering knowledge; Management, and Multidisciplinary knowledge (all reported once) are also among top impact skills by EDC as compared with University.

### *7.2. Qualitative Main Findings*

EDC have been reported by both students and instructors to have a positive impact on 22 out of 23 competencies of 21st century engineers (no significance was captured in "Math, Sciences, and Phsysics"). EDC major positive impact was found on the following competencies: Communications, Management, Teamwork, Inter- and Multi-disciplinary knowledge, Practical Experience, and Decision Making.

### *7.3. Convergence of Data Streams and Findings*

The investigation utilized a mixed methods approach based on quantitative and qualitative data; both data streams have led to significantly similar findings. Qualitative data shed further in-depth understanding on several aspects not covered in the quantitative surveys. It is also worth mentioning that perspectives of students and instructors have converged in most cases as well in the qualitative data.

## **8. Discussions and Limitations**

The study highlighted several engineering learning values of the design competition. The engineering learning value of design competitions have been emphasized in several other studies. Such values includes, among others, integrating theories from different courses into applicable development, computer aided design, practical experience, industry-like authentic experience, interdisciplinary engineering experience [10–13,49–52]. The educational benefits in engineering learning of design competitions can be understood from the perspective of learner-centric, experiential, project-based, and constructivist pedagogy theories [53–58]. There are couple of pillars of constructivist pedagogy in which are significantly implemented through complex design projects.

One of the main findings of the project is the fact that students in all five investigated groups have highlighted EDC to have further developmental impact on their competencies than University. This has been rather consistent in both quantitative and qualitative data streams. It can be stated also with a significant confidence that the level of engagement of students in EDC is higher than in University experience (e.g., courses, assignments, etc.). The hands-on and collaborative experience (two core constructivist principles) of EDC are probably the two most correlated factors for such differences. Modern constructivist pedagogy emphasizes on several aspects that are highly observed in experiences such EDC. For instance authentic learning, learning by doing, self-construction of knowledge, and social nature of learning are some of the most differentiating factors of constructivism. Universities who could adapt more constructivist experiences such as EDC may have significant higher engagement and graduate outcomes.

One of the most important reasons that made students to participate was enhancement of their engineering skills. Students have significant positive perception on EDC experience in contributing significantly to a wide range of technical, soft, cognitive, professional, leadership, and business oriented competencies. The majority of reported enhanced skills as a result of EDC experience are not only recommended for the workplace, but also as generic requirements of knowledge based economy citizens [15]. Findings of the EDC experience impact in Shell Eco-Marathon can be largely generalized with a significant confidence to any similar complex engineering design competition. Generalization into complex engineering design experiences without a competition factor or international exposure can be done, however we expect some differences due to the lack of competition factor, this may require more research to verify. For instance, in EDCs the goal of design project is well-defined and clear standards should be followed (e.g., formula automotive standards in Formula SAE, safety standards, energy efficiency standards, cost standards, etc.), also in EDCs, evaluation criteria is normally well-defined. Another distinguishing factor in EDCs is the fact that students are developing designs and products to compete regionally or globally with other teams of students from several reputable Universities and from different countries; this increases the motivation to produce the highest possible quality designs and products. The award system in EDCs is another motivating factor, since winning the competition is a significant indicator of regionally or globally competent level of the winning students team. The opportunity of social learning in EDCs is intense and significantly higher that in none-competition projects due to the large number of competing teams every year. Normally EDCs also provide multiple pathways for winning awards, such as performance awards, design awards, communications awards, business awards, safety awards, technical innovation award, event spirit award, etc. and hence students may try to excel on various aspects that would not normally pay attention for in normal design projects.

A main limitation of the study is reliance mainly on students reports (quantitative and qualitative) in addressing the EDCs impact; however additional evidence through faculty observations reports (from the interviews) and from various literature have added another supporting data stream on the findings. Another limitation is that most participants are self-select to participate; this could introduce a bias in the data due to the intrinsic motivation of the sample group, and subsequently in the findings. Controlled experiment would be necessary to investigate possible differences between samples with intrinsic motivation to participate, and samples with no-interest to take part in EDCs. Our expectation is that both samples may demonstrate a relatively close outcomes, however the no-interest group may take longer time until getting immersed in the experience and then start constructing knowledge and skills.

Despite the several benefits of automotive EDCs, they come with significant limitations that may hinder scaling them up across the engineering education system. For instance, cost of cars development is significantly high in terms of needed money, materials, travel and shipping, and time commitment (for both faculty and students). Many engineering schools also may lack basic competencies, infrastructure, and business capabilities to jump-start such projects. SAE has developed another version of Formula EDC called Formula Low Cost in which the limitation on car cost development is addressed. Coverage of additional financial costs for development, travel, etc. would need a more entrepreneurial approach from both students and faculty in order to guarantee sponsorship for the EDCs from partner industry, however again this will have additional time commitment cost.

## 9. Conclusions and Future Work

This study has shown new perspectives of complex design impact, here on 21st century engineering skills development. The reported perceived impact of complex design experience on 21st century competencies development was higher than the impact of conventional university experiences by all surveyed groups (ME, Asia, EU, Male, and Female). The highest developmental impacts of EDC was observed in the following measures: 1—Practical experience; 2—Teamwork; 3—Creative thinking; and 4—Decision making; 5—Problem solving; 6—Professionalism; 7—Analytical thinking; 8—Systems thinking; 9—Leadership; and 10—ICT skills. The importance of this study stem in two main dimensions, first it sheds a light on the core importance of embedding design in engineering curriculum, and second it shows that design also plays as a vehicle for developing a whole other set of soft competencies considered necessary for sustainable knowledge based economy development; In particular there is scarcity of research on engineering design impact on non-technical skills development. Furthermore, in-depth research on the impact of complex engineering design experience on soft skills development and the mechanism in which these skills are developed is highly recommended, for instance using sophisticated tools such as psychometric instruments, observational metrics, video records, meta-case studies analysis, etc. In addition, another stream of recommended research would be to investigate differences in EDCs and other engineering design projects and analyze routes and causes of such differences. Finally, future research studies may focus on best approaches for designing engineering design competitions and their award systems in order to maximize their benefits to the multiple stakeholders involved as well as accommodating for additional values and developmental impacts EDCs could bring.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Appendix A. List of Reports on Technical and Engineering Learning Taking Place in Automotive EDCs

**Table A1.** Reports on engineering design competitions published in various countries.

| Type of Dissemination | Name | Country | Focus |
|---|---|---|---|
| Patent | A System for Generating Electrical Power Using Fuel Cells and an Improved Method for Generating Electric Power Using Fuel Cells | Denmark | Technical |
| Conference Paper | Combined Electric Applications in Transport | Belgium | Technical |
| Conference Paper | Designing the Car of the Future | Canada | Technical |
| Conference Paper | Student Learning Projects in Electric Vehicle Engineering | Denmark | Technical/Educational |
| Conference Paper | Model Predictive Real-Time Controller for a Low-Consumption Electric Vehicle | France | Technical |
| Conference Paper | Structural Optimization of Fiber-Reinforced Composites for Ultra-Lightweight Vehicles | Germany | Technical |
| Conference Paper | Modeling and Control of the Energy Consumption of a Prototype Urban Vehicle | Greece | Technical |
| Conference Paper | Recent advances on the energy management of a Hybrid Electric vehicle | Greece | Technical |
| Conference Paper | New Technologies Demonstrated at Formula Electric and Hybrid Itlay 2008 | Italy | Technical |
| Conference Paper | The Impact on Quality of Students Through Participation in International Challenge Project—A Case Study on UKM's | Malaysia | Technical |
| Conference Paper | Getting Students Hooked on Systems Engineering | Norway | Technical |
| Conference Paper | Shell Eco Marathon 2009 Electric Drive for World's Most Fuel Efficient Car | Norway | Technical |
| Conference Paper | Electric Vehicle for the Students' Shell Eco-Marathon Competition; Design of the Car and Telemetry System | Poland | Technical |
| Conference Paper | Miniaturized Cylinder Head Production by Rapid Prototyping | Portugal | Technical |
| Conference Paper | Transient Thermal Behavior of Insulated and Non-Insulated M3165 Internal Combination Engine in SEM Prototype Vehicle | Portugal | Technical |
| Conference Paper | Design of Qatar University's First Solar Car for Shell Eco-Marathon Competition | Qatar | Technical |
| Conference Paper | Implementing Advanced CAE Tools in Automotive Engineering Education at Chalmers University of Technology | Sweden | Technical |
| Conference Paper | A Sustainable Approach to Advanced Energy and Vehicular Technologies at the University of Kansas | USA | Technical |
| Conference Paper | Participation in a Fuel Efficiency Competition for the Mechanical Engineering Capstone Design Experience | USA | Technical |
| Journal Articles | Design and Testing of a Fuel Cell Powertrain with Energy Constraints | France | Technical |
| Journal Articles | Optimalisation the Position of Solar Cells for Vehicles | Hungary | Technical |
| Journal Articles | A Shell Eco-Marathon Concept Car Engine Design | Nigeria | Technical |

## Appendix B. Survey Sample

**21st Century Engineering Skills**

14. To which extent do you Agree or Disagree that University Study and Shell Eco Marathon Competition contributes to the development of the following skills tabulated below: "1= Strongly Disagree (SD)", "2= Disagree (D)", "3= Neutral", "4= Agree (A)", "5= Strongly Agree (SA)"

| *University Study Experience (pre-SEM)* ← | COMPETENCIES of ENGINEERING GRADUATES | *Shell Eco Marathon Experience* → |
|---|---|---|
| SA A N D SD | | SD D N A SA |
| 5 4 3 2 1 | CORE ENGINEERING KNOWLEDGE & PRACTICE | 1 2 3 4 5 |
| ☐ ☐ ☐ ☐ ☐ | **DISCIPLINARLY ENGINEERING FUNDAMENTALS (Depth)** *"Demonstrate in-depth technical knowledge in the engineering field of specialty and know-how in specific engineering discipline and apply this knowledge effectively through practice – in balance with non-technical skills"* | ☐ ☐ ☐ ☐ ☐ |
| ☐ ☐ ☐ ☐ ☐ | **INTERDISCIPLINARY ENGINEERIGN KNOLWEDGE (Breadth)** *"Develop and build a multidisciplinary knowledge from other engineering fields and a comprehensive interdisciplinary knowledge from a specific filed through a scholarly approach that incorporating theory and practice"* | ☐ ☐ ☐ ☐ ☐ |
| ☐ ☐ ☐ ☐ ☐ | **MATH, PHYSICS, & SCIENCE FUNDAMENTALS** *"Demonstrate essential mathematical skills and use, quantify, and manipulate numbers and their application accurately in any contexts"* | ☐ ☐ ☐ ☐ ☐ |
| ☐ ☐ ☐ ☐ ☐ | **PRACTICAL EXPERIENCE** *"Apply knowledge and skills, required for effective professional engineering practices, into real-world settings"* | ☐ ☐ ☐ ☐ ☐ |
| ☐ ☐ ☐ ☐ ☐ | **ICT EXPERIENCE** *"Use information and communication technology applications interactively in locating, managing, modeling, analyzing, evaluating, and processing information from multiple sources to effectively accomplish a given task"* | ☐ ☐ ☐ ☐ ☐ |
| ☐ ☐ ☐ ☐ ☐ | **MULTIDISCIPLINARY KNOWLEDGE (Outside the engineering fields, e.g. social, humanities, business, etc.)** *"Develop and build a multidisciplinary knowledge from other engineering fields and a comprehensive interdisciplinary knowledge from a specific filed through a scholarly approach that incorporating theory and practice"* | ☐ ☐ ☐ ☐ ☐ |

**Figure A1.** Sample of question structure regarding skills perception.

## Appendix C. Statistics of comparison between EU, Asian, and ME Students

**Table A2.** Dimension I: Core Engineering knowledge and practice. European and Asian Students engineering perceptual scores of EDC post participation on 21st century skills (1st dimension) development. All ratings are achieved based on a scale from 1 to 5, where 5 is the highest.

| Variable | Mean | | Sample Number ($n$) | $p$-Value (Mann Whitney U Test) | Statistical Significance |
|---|---|---|---|---|---|
| Disciplinarily Engineering Fundamentals (Depth) | European<br>Asian | 3.96<br>4.13 | 129<br>104 | 0.093 | No |
| Interdisciplinary Engineering Knowledge (Breadth) | European<br>Asian | 3.95<br>4.16 | 129<br>104 | 0.110 | No |
| Math, Physics, and Science Fundamentals | European<br>Asian | 3.51<br>4.06 | 126<br>104 | 0.016 | Yes |
| Practical Experience | European<br>Asian | 4.36<br>4.35 | 128<br>105 | 0.880 | No |
| ICT Experience | European<br>Asian | 3.67<br>3.97 | 128<br>99 | 0.011 | Yes |
| Multidisciplinary Knowledge | European<br>Asian | 3.77<br>3.98 | 126<br>98 | 0.109 | No |

**Table A3.** Dimension III Core Engineering knowledge and practice. European and Asian Students engineering perceptual scores of EDC post participation on 21st century skills (3rd dimension) development. All ratings are achieved based on a scale from 1 to 5, where 5 is the highest.

| Variable | Mean | | Sample Number ($n$) | $p$-Value (Mann Whitney U Test) | Statistical Significance |
|---|---|---|---|---|---|
| Professionalism | European<br>Asian | 3.94<br>4.21 | 124<br>101 | 0.029 | Yes |
| Ethics and Responsibility | European<br>Asian | 3.72<br>4.21 | 124<br>101 | 0.000 | Yes |
| Adaptability | European<br>Asian | 4.09<br>4.21 | 123<br>100 | 0.434 | No |
| Communication | European<br>Asian | 3.89<br>4.30 | 123<br>101 | 0.002 | Yes |
| Teamwork | European<br>Asian | 4.33<br>4.36 | 123<br>100 | 0.949 | No |

**Table A4.** Dimension IV Business. European and Asian Students engineering perceptual scores of EDC post-participation on 21st Century skills (4th dimension). All ratings are achieved based on a scale from 1 to 5, where 5 is the highest.

| Variable | Mean | | Sample Number ($n$) | $p$-Value (Mann Whitney U Test) | Statistical Significance |
|---|---|---|---|---|---|
| Management | European<br>Asian | 3.72<br>4.08 | 122<br>100 | 0.002 | Yes |
| Leadership | European<br>Asian | 3.87<br>4.18 | 123<br>100 | 0.007 | Yes |
| Entrepreneurship | European<br>Asian | 3.64<br>4.07 | 123<br>100 | 0.002 | Yes |

**Table A5.** Dimension I: Core Engineering knowledge and practice. Middle Eastern and European Students engineering perceptual scores of EDC post-participation on 21st century skills (1st dimension). All ratings are achieved based on a scale from 1 to 5, where 5 is the highest.

| Variable | Mean | | Sample Number ($n$) | $p$-Value (Mann Whitney U Test) | Statistical Significance |
|---|---|---|---|---|---|
| Disciplinarily Engineering Fundamentals (Depth) | Middle eastern<br>European | 4.30<br>3.96 | 30<br>129 | 0.038 | Yes |
| Interdisciplinary Engineering Knowledge (Breadth) | Middle eastern<br>European | 4.23<br>3.95 | 30<br>129 | 0.140 | No |
| Math, Physics, and Science Fundamentals | Middle eastern<br>European | 3.87<br>3.51 | 30<br>126 | 0.151 | No |
| Practical Experience | Middle eastern<br>European | 4.52<br>4.36 | 29<br>128 | 0.129 | No |
| ICT Experience | Middle eastern<br>European | 3.90<br>3.67 | 31<br>128 | 0.211 | No |
| Multidisciplinary Knowledge | Middle eastern<br>European | 4.16<br>3.77 | 31<br>126 | 0.029 | Yes |

**Table A6.** Dimension II: Cognition thinking and mental. Middle Eastern and European Students engineering perceptual scores of EDC post-participation on 21st skills (2nd dimension). All ratings are achieved based on a scale from 1 to 5, where 5 is the highest.

| Variable | Mean | | Sample Number (*n*) | *p*-Value (Mann Whitney U Test) | Statistical Significance |
|---|---|---|---|---|---|
| Lifelong Learning | Middle eastern<br>European | 3.97<br>3.86 | 31<br>123 | 0.454 | No |
| Problem Solving | Middle eastern<br>European | 4.29<br>4.21 | 31<br>125 | 0.438 | No |
| Decision Making | Middle eastern<br>European | 4.32<br>3.98 | 31<br>123 | 0.040 | Yes |
| Analytical Thinking | Middle eastern<br>European | 4.10<br>3.98 | 30<br>125 | 0.170 | No |
| Systems Thinking | Middle eastern<br>European | 4.30<br>3.90 | 30<br>125 | 0.025 | Yes |
| Critical Thinking | Middle eastern<br>European | 4.20<br>3.94 | 30<br>125 | 0.138 | No |
| Creative Thinking | Middle eastern<br>European | 4.41<br>4.15 | 29<br>125 | 0.071 | No |
| Innovation | Middle eastern<br>European | 4.47<br>3.97 | 30<br>125 | 0.003 | Yes |
| Design | Middle eastern<br>European | 4.47<br>3.97 | 30<br>125 | 0.004 | Yes |

**Table A7.** Dimension IV: Business. Middle Eastern and European Students engineering perceptual scores of EDC post-participation on 21st Century skills (4th dimension). All ratings are achieved based on a scale from 1 to 5, where 5 is the highest.

| Variable | Mean | | Sample Number (*n*) | *p*-Value (Mann Whitney U Test) | Statistical Significance |
|---|---|---|---|---|---|
| Management | Middle eastern<br>European | 4.39<br>3.72 | 28<br>122 | 0.000 | Yes |
| Leadership | Middle eastern<br>European | 4.31<br>3.87 | 29<br>123 | 0.007 | Yes |
| Entrepreneurship | Middle eastern<br>European | 4.24<br>3.64 | 29<br>123 | 0.002 | Yes |

## Appendix D. Statistics of In-Group Wilcoxon Test and Gaps Analysis

**Table A8.** Dimension II: Cognition thinking and mental. Perceptual gaps in 21st century skills 2nd dimension between European, Asians and Middle Eastern as well as genders comparing university studies and post EDC participation.

| Variable | Group under Study | Perceptual Gap/Wilcoxon | Gender | Perceptual Gap/Wilcoxon |
|---|---|---|---|---|
| Lifelong Learning | European<br>Asian<br>Middle eastern | 0.4/0.000<br>0.66/0.000<br>0.44/0.131 | Male<br>Female | 0.58/0.000<br>0.38/0.004 |
| Problem Solving | European<br>Asian<br>Middle eastern | 0.76/0.000<br>0.58/0.000<br>0.85/0.001 | Male<br>Female | 0.75/0.000<br>0.53/0.000 |

**Table A8.** *Cont.*

| Variable | Group under Study | Perceptual Gap/Wilcoxon | Gender | Perceptual Gap/Wilcoxon |
|---|---|---|---|---|
| Decision Making | European | 0.80/0.000 | Male | 0.80/0.000 |
| | Asian | 0.70/0.000 | Female | 0.67/0.001 |
| | Middle eastern | 0.91/0.002 | | |
| Analytical Thinking | European | 0.30/0.000 | Male | 0.57/0.000 |
| | Asian | 0.78/0.000 | Female | 0.34/0.007 |
| | Middle eastern | 0.58/0.080 | | |
| Systems Thinking | European | 0.49/0.000 | Male | 0.66/0.000 |
| | Asian | 0.78/0.000 | Female | 0.49/0.001 |
| | Middle eastern | 0.69/0.005 | | |
| Critical Thinking | European | 0.60/0.000 | Male | 0.71/0.000 |
| | Asian | 0.71/0.000 | Female | 0.46/0.001 |
| | Middle eastern | 0.65/0.022 | | |
| Creative Thinking | European | 0.87/0.000 | Male | 0.86/0.000 |
| | Asian | 0.79/0.000 | Female | 0.67/0.000 |
| | Middle eastern | 0.71/0.005 | | |
| Innovation | European | 0.61/0.000 | Male | 0.72/0.000 |
| | Asian | 0.73/0.000 | Female | 0.53/0.001 |
| | Middle eastern | 0.79/0.003 | | |
| Design | European | 0.60/0.000 | Male | 0.71/0.000 |
| | Asian | 0.70/0.000 | Female | 0.50/0.002 |
| | Middle eastern | 0.82/0.006 | | |

**Table A9.** Dim III: Professional and interpersonal. Perceptual gaps in 21st century skills 3rd dimension between European, Asians and Middle Eastern as well as genders comparing university studies and post EDC participation.

| Variable | Group under Study | Perceptual Gap/Wilcoxon | Gender | Perceptual Gap/Wilcoxon |
|---|---|---|---|---|
| Professionalism | European | 0.51/0.000 | Male | 0.57/0.000 |
| | Asian | 0.58/0.000 | Female | 0.59/0.000 |
| | Middle eastern | 0.88/0.001 | | |
| Ethics and Responsibility | European | 0.38/0.000 | Male | 0.58/0.000 |
| | Asian | 0.72/0.000 | Female | 0.42/0.007 |
| | Middle eastern | 0.64/0.010 | | |
| Adaptability | European | 0.74/0.000 | Male | 0.73/0.000 |
| | Asian | 0.72/0.000 | Female | 0.64/0.001 |
| | Middle eastern | 0.71/0.005 | | |
| Communication | European | 0.68/0.000 | Male | 0.73/0.000 |
| | Asian | 0.69/0.000 | Female | 0.53/0.006 |
| | Middle eastern | 0.71/0.004 | | |
| Teamwork | European | 0.97/0.000 | Male | 0.95/0.000 |
| | Asian | 0.81/0.000 | Female | 0.77/0.000 |
| | Middle eastern | 1.02/0.000 | | |

**Table A10.** Dimension IV Business. Perceptual gaps in 21st century skills 4th dimension between European, Asians and Middle Eastern as well as genders comparing university studies and post EDC participation.

| Variable | Group under Study | Perceptual Gap/Wilcoxon | Gender | Perceptual Gap/Wilcoxon |
|---|---|---|---|---|
| Management | European | 0.69/0.000 | Male | 0.73/0.000 |
| | Asian | 0.57/0.000 | Female | 0.41/0.007 |
| | Middle eastern | 0.89/0.002 | | |
| Leadership | European | 0.66/0.000 | Male | 0.76/0.000 |
| | Asian | 0.74/0.000 | Female | 0.48/0.010 |
| | Middle eastern | 0.68/0.015 | | |
| Entrepreneurship | European | 0.38/0.000 | Male | 0.6/0.000 |
| | Asian | 0.69/0.000 | Female | 0.35/0.009 |
| | Middle eastern | 0.64/0.025 | | |

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