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The Role of the Capstone Project in Engineering Education in the Age of Industry 4.0 - A Case Study

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Abstract: The capstone project in many academic institutions is the high point of undergraduate studies in engineering. The transition of graduates to industry is still not optimal, and there is a disparity between the needs of industry and the actual ability of academia to meet these needs. This study examines the role of the capstone project as a pedagogical tool in the age of Industry 4.0 in the field of product development, and as a bridge between academia and industry. The study combines qualitative and quantitative methods, focusing on four stakeholders (academia, industry, students and advisors). The study is based on several sources, such as: semi-structured interviews, questionnaires, observations, and more. The study results indicate that the capstone project is important and valuable for industry and academia, as well as being perceived by students as the most important undergraduate course. Nevertheless, the results reveal that it has many gaps and shortcomings and illuminate the need for a deep perceptual and structural change. Academia should reconsider projects' length and define milestones in which independent learning is optimally enabled. The projects' contribution to academic institution reputation, should be considered when defining the project goals. Coping with the challenges and gaps found in this study, the project can also be used in order to reduce incongruities, while preparing the students in a better way for their professional role in changing environment.

Keywords: *Academic-Industry relationship; Capstone projects [syn: Senior project]; Engineering Education; Industry 4.0; Instructional methods [syn: Pedagogy]; Professional skills [syn: Soft skills].*

Introduction

The fourth industrial revolution (Industry 4.0) has produced major transformations in industry. As part of the increased availability of knowledge and information, the field of product development (durable goods) has undergone many transitions that require academia to adapt itself to the revolution’s changes so that graduating students will be capable of dealing with technological advances and their impact (González & Calderón, 2018; Umachandran et al., 2019). In many academic institutions, the capstone project serves as the high point of undergraduate studies in engineering. The project is supposed to summarize the knowledge accumulated by students, train them for engineering challenges, and enable a smooth transition to the professional world (Howe & Goldberg, 2019; Hauhart & Grahe, 2015; Shacham & Davidovitch, 2010). In many cases, the capstone project includes the development of a physical product, and the project simulates the product development process in industry. In light of Industry 4.0 changes, fundamental modifications to the capstone project could logically be expected, however the project has remained nearly unchanged for years. Consequently, calls are being heard in academia to cancel the project as it has been reduced to a merely “traditional” exercise, and the question is whether or not this type of project can continue to provide value in the future.

The purpose of this study is to examine the capstone project as a pedagogical tool in the age of Industry 4.0 in the field of product development (focusing on mechanical engineering), and how it can better prepare students' transition from academic studies to the practical world. The study focuses on and examines the impact of industry, project advisors, students, and policy makers from the academic community. The results may contribute to developing new teaching methods in the field of product development, help reduce the gaps between academia and industry, assist new graduates entering industry, and serve as a tool for decision makers in an academic institution with regard to designing the capstone project.

Theoretical Framework and Literature Review

In the fourth industrial revolution, the integration of innovative technologies is blurring the borders between the physical and the digital elements. New technologies such as IoT (Internet of Things), AI (Artificial Intelligence), robotics, 3D printing, nanotechnology, and others (Diwan, 2017) result in frequent breakthroughs at an exponential pace (Shwab, 2016), resulting in smart factories with man-machine combinations. Information is accessible to all, and pedagogical adaptation to contemporary changes is critical and essential for academia in order to remain relevant (González & Calderón, 2018; Umachandran et al., 2019).

The Process of Training Engineers in Academia

Engineering studies comprise four-year academic training programs, culminating in a Bachelor of Science degree (B.Sc.). One of the prominent teaching methods in these programs is project/problem-based learning (PtBL/PmBL), where students are required to show skills of research and discovery, teamwork, and creativity in developing products (Todd, Sorensen, & Magleby, 1993; Akili, 2011). In the past decade, researchers have focused intensively on the significance of developing student's various proficiencies, in addition to expanding theoretical knowledge, such as flexible thinking, creativity, independent learning, and entrepreneurship (Davidovitch & Shiller, 2016; Moon-Soo, 2015; Munakata & Vaidya, 2015). Other features of PtBL/PmBL are related to developing innovations skills and interdisciplinarity (Hotaling, Fasse, Bost, Hermann, & Forest, 2013; Zaher & Damaj, 2018). Over the years, these processes have been congruent with the STEM (science, technology, engineering, and mathematics) approaches that relate to the integration of knowledge and skills between several scientific disciplines through different learning styles, and connecting the academic contents to actual circumstances (Breiner, Harkness, Johnson & Koehler, 2012).

The Capstone Projects

Among the various courses and projects that utilize the PmBL/PtBL method, the capstone project occupies a prominent place. In the 1970s, the capstone project was included in only 3% of all academic institutions. In the 1980s and 1990s there was a sharp rise in its popularity, and in the past few years, researchers estimate that the project is suggested or required in about 66%-75% of all engineering programs (Hauhart & Grahe, 2015).

The capstone project serves as a tool for learning new contents and for evaluating the student's ability to deal with an engineering task. The project grants a relatively large number of academic credits and requires considerable efforts both from the students and the academic institution, regarding logistics, time, and means (Shacham & Davidovitch, 2010). However, it appears that the project has hardly changed at academic institutions over the years, aside from slight adaptations, and most of the changes are in the project topics rather than in its essence or structure (Shurin, Davidovitch, & Shoval, 2019).

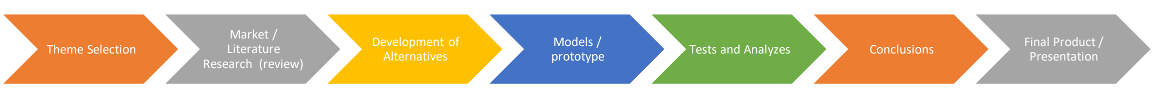
The Process of the Capstone Project

As seen in Figure 1, the process usually includes several major milestones. Capstone projects are generally conducted in a similar way to the structure elaborated in this study, and the development process is generally similar in different institutions. This structure provides the students with an opportunity to experience a full product development process with all its aspects and stages (Shiller, 2013). The capstone project is conducted individually or in pairs, with an advisor. Topics can be selected from a list of alternatives proposed by advisors, by industry, or by the students. In some cases, collaborating in a group assignment (departmental/ multi-departmental) is also possible.

Students' work begins by analyzing the essence of the project and its aims, planning a detailed work plan and schedule, and reviewing the products or approaches in the specific field. Students must develop design alternatives, submit monthly reports, produce models for testing, and carry out tests. When the design is completed, the students produce a prototype and submit a report, which includes the relevant information. In many cases, some or all projects are displayed in an exhibition.

Figure 1

Key Milestones in the Capstone Project Development Process



Challenges in Teaching the Capstone Project

Already in the early 2000s, researchers began to question the relevancy of the capstone project (Hauhart & Grahe, 2015). In recent years its future has been discussed, and some researchers are calling for cancellation of the entire project (Saar, 2011). Following Industry 4.0 changes, an essential transformation may have been expected in the capstone project, its structure and outcomes. This fact contradicts the contention that the capstone project is a product of its context and must therefore respond to changes only in its enveloping surroundings in order to be successful (Hauhart & Grahe, 2015). Moreover, it is apparent that the clear goal of all those engaged in "preparing students for their role in industry" suffers from a lack of clarity regarding its interpretation and translation into action.

The Transition from Academic Studies to Industry

Dym et al. (2005) claim that one of the main goals in engineering education is to "produce" engineers with design capabilities. Students too expect to complete their studies with the best skills for a professional job in industry. This expectation is also supported by industry, which expects graduates to demonstrate professional abilities and adequate skills for the contemporary world.

As part of the Industry 4.0 revolution and the increasing accessibility of knowledge and information, developing products in global markets is undergoing many transformations. Beyond the technological innovations, it is also possible to see:

- A higher quantity and frequency of products emerging in the markets;
- A shortened and innovated development process of new products;
- The impact of competition, changes, and constraints of the technological, entrepreneurial, and social world on the development processes;
- The wide availability of professional knowledge and more rapid exposure to new knowledge.

In light of these changes, graduating students face competition in a very diverse, technological, and multi-cultural world (Umachandran et al., 2019). Studies show that product development requires a different academic graduate with different multidisciplinary abilities. Graduates must have "classical" professional skills while adjusting to technology, production, manner of use and the user environment, and the ability to best utilize the resources available to them (Craig & Voglewede, 2010). In addition, they need "soft" capabilities such as a wide perspective, and the ability to manage projects (Soares, Sepúlveda, Monteiro, Lima, & Dinis-Carvalho, 2013). The World Economic Forum listed the ten qualities and capabilities necessary for workers in 2020, such as solving complex problems and critical thinking (Gray, 2016). Table 1 summarizes the capabilities and requirements of engineers in the age of the fourth industrial revolution (taken from several sources).

Incongruence between Academia and Industry in the Field of Project Development

Key areas where academia is not keeping pace with industry include:

- Product complexities and product development scheduling;
- Product requirements: not only functionality and reliability, but also innovation, user experience, and subjective and emotional features (Sadeh, 2010).
- User Centered Design. Emphasis on the user needs and goals, and expectation of development teams to 'get into user's shoes' (Lanter & Essinger, 2017; Miaskiewicz & Kozar, 2011).
- Innovative thinking methods and new development processes: such as the AGILE and LEAN methods.

Table 1

Capabilities Required of Engineers

"The Future of Jobs" – World Economic Forum (Gray, 2016)	**Engineering Education Forum** (Bentur, Zonnenshain, Nave & Dayan, 2019)	**Forbes** (Beckford, 2018)	**Selected Capabilities Mentioned in the Literature Review**
Solving complex problems	Critical thinking	Analyzing information	Multidisciplinary abilities
Critical thinking	Creativity	Ability to identity patterns and trends	Ability to optimally develop a product
Creativity	Teamwork	Learning how to learn	Optimal utilization of resources
Managing people	Internationalization		Identifying needs
Conduct and coordination with others	Solving complex problems		Creativity
Emotional intelligence	Communication		Innovativeness
Decision making			Wide perspective
Service orientation			Ability to manage projects
Negotiation ability			
Flexible thinking			

Attempts to Bridge the Gap between Academia and Industry

Manners of Coping in Industry

The disparities between the needs of industry and graduates' skills and knowledge are evident. There are various attempts to cope with this gap. Industry provides opportunities for students to gain experience in their professional field while still completing their studies ("student internship"). Approximately 75% of engineering students work during their studies, 50% of those work in the professional field of their studies (Bentur, Zonnenshain, Nave, & Dayan, 2019). In addition, there are many collaborations between industry and academia (mostly serving joint interests). In these collaborations, joint work is carried out towards developing new products, brainstorming for new concepts, and research related to the field of the commercial firm. Also, industry copes with these disparities by providing workplace mentoring for recent graduates by a more senior worker.

Manners of Coping in Academia

"Lifelong learning" is becoming part of the outcome-based education (OBE) method, which emphasizes self-learning that eventually leads to a continuous, self-motivated and voluntary process (Bentur, Zonnenshain, Nave, & Dayan, 2019; Kanmani & Babu, 2015; Umachandran et al., 2019). Any career chosen by students after graduation (as a salaried employee in industry, an entrepreneur, a researcher, or an academic) will probably involve tasks that require independent learning (Kanmani & Babu, 2015). This is also critical in light of Industry 4.0, where the new technologies of the present may change in the future and thus have a fundamental impact on the form and essence of the work (Umachandran et al., 2019).

Research Methodology

The study examines the capstone project in an undergraduate mechanical engineering program, while striving to answer the following questions:

1. What is the role of the capstone project (in the field of product development) as a learning tool?
2. What are the necessary skills for students upon graduation?
3. What are the disparities between the product development process of capstone project in academia and in industry?
4. Can the capstone project be used as a tool for reducing incongruences between academia and industry, and how?
5. Is there a need for a change in the project in light of industry's changes and demands?

The study combines qualitative and quantitative methods in a case study that follows the process carried out in an engineering college. This college implements the project/problem-based teaching technique and about 15% of the undergraduate courses follow this method (Shamoon College of Engineering, 2018). Additional academic institutions were examined in order to reinforce the study and to receive a wider picture. The study incorporates several sources, described below.

1. Semi-structured, in-depth interviews with about 20 key people from four groups: industry, project advisor, representatives of the academic institution (deans and department heads), and graduates. The interview addresses four main topics, with about 10 questions per topic. Each interview lasts between 30 minutes to an hour. The interviews were conducted as a peer dialogue and the anonymity of the interviewees was maintained. Interviewees from academia were recruited according to the key positions they hold, and their relevancy to the study topic (project advisors / heads of departments / deans). Interviewees from industry were recruited according to their position, seniority and experience. The graduate interviewees were recruited according to their place of study, their current workplace, and the capstone project they did during their studies (physical products only).
2. Student Questionnaire – administered to about 80 fourth-year mechanical engineering students (about 40 capstone project teams) during their capstone project. The questionnaire examined their perception of the project, necessary capabilities, its contribution, and more. About 85% of the respondents were men and 15% women. The average age was 27.9 and 95.8% carried out the project in couples, and the rest independently. The students received no remuneration for the answers. The questionnaire comprised 15 questions and was filled out online using Google Forms. For 14 of the questions, students were asked to mark their answers on a Likert scale of 5 (5 – the highest extent; 1 – not at all), question #1 was an "open question" about the student's general plans after graduation. The ordinal data was analyzed by the Spearman's correlation coefficient that is a nonparametric measure of rank correlation, which measures the degree of association between two variables based on their ranks.

   The questionnaire was divided into four groups of indices:

- The importance and perceptions of the project: (questions 2, 14, 15).

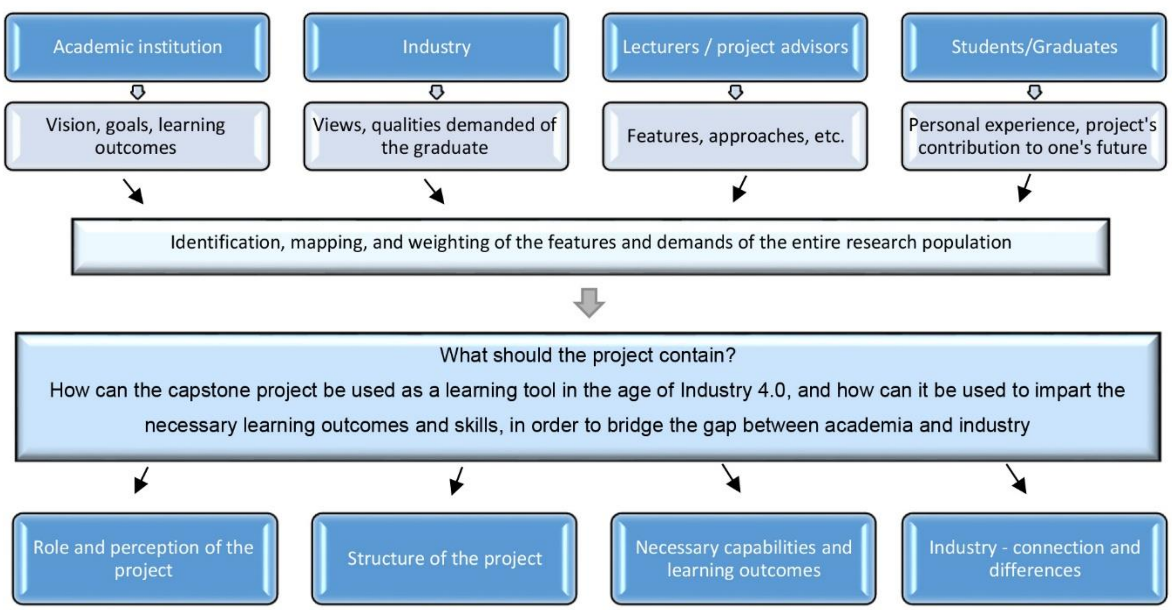
- Project structure and timeline: (questions 10, 11, 12, 8).
- Coping with new challenges and acquired learning skills (Questions 3, 4, 5, 9).
- Guidance: (questions 6, 7, 11).

Active participation in supervising capstone projects, and observations of the process accompaniment by the advisors. Participation and observation in conferences, exhibitions and panels.
Documents of the Council for Israeli Higher Education (2018-2019) and of the academic college of engineering studied.

Review of theoretical literature on the capstone project in higher education, disparities between academia and industry, and attempts to deal with this disparity.

As shown in Figure 2, the study focuses on and examines four main stakeholders and their impact on the field: policy makers of the academic institution, industry representatives, project advisors and the students / graduates. With each stakeholder, the research questions were examined, in light of four main issues: the role and perception of the project; project structure; learning outcomes and skills required; academy vs Industry - connection, differences, needs and dealing with gaps.

Figure 2
Research Model



Previous studies (e.g. Shacham and Davidovitch (2010), and Heller-Hayun, Davidovitch, and Shoval (2011)) examined the gaps between the knowledge acquired in the curriculum in diverse programs from engineering studies and the knowledge required in industry for graduates of electrical and electronics engineering, mechanical engineering, industrial and management engineering, chemical engineering, and civil engineering. In contrast, the current study focuses only on the capstone project in mechanical engineering studies, examining it as a tool for reducing the gaps, its role and students' perceptions about it.

In the study by Shacham and Davidovitch, the effectiveness of the capstone project was evaluated, and the degree to which it met expectations from the academic side. Here we examine the project with reference to all relevant stakeholders (industry, supervisors, students, graduates and the academic institution). Also, in the previous studies the focus was on graduates after graduation, examining their retrospective opinions on the project, whereas in the current study a new perspective is obtained by examining students while they are carrying out the project during their studies, and obtaining their perceptions of the contribution of the project in preparation for their future careers.

Results

Questionnaire Results

The general reliability of the students' responses to the questionnaire was α=0.81. The reliability of the indices described in the previous section are**:**

- The importance and perceptions of the project: α= 0.73.
- The project's times and its structure: α= -0.82
- Coping with new challenges and acquired learning skills: α= 0. 84.
- Guidance: α= 0.81.

Table 2 provides statistical data on the response to the questionnaire.

About 82% of the students think that the project prepares them for industry in a medium-high degree, and 74% would recommend another student to perform the project even if it was an elective course. These findings support the findings of Heller-Hayun, Davidovitch and Shoval, who showed that nearly 90% of the graduates believe that the capstone project is important in training the engineer. About 87% of the students were exposed to new challenges during the project, and about 85% of them managed to cope with new challenges during the project to a large extent.

Table 2

Statistical Data from the Questionnaire Responses

Q	MIN	MAX	MEAN	MEDIAN	SD
2	1	5	3.846	4	0.904
3	1	5	4.315	5	0.933
4	1	5	4.263	4	0.890
5	1	5	3.71	4	1.088
6	1	5	4.052	4.5	1.137
7	1	5	3.868	4	1.143
8	1	5	3.868	4	1.143
9	2	5	4.131	4	0.875
10	1	5	2.789	3	1.297
11	1	5	2.868	3	1.189
12	1	5	2.078	1.5	1.343
13	2	5	4.526	5	0.761
14	1	5	3.473	4	1.083
15	1	5	3.421	4	1.328

Table 3 lists the Spearman correlation coefficient of the questionnaire. The strong correlations between questions 2 and 4, 2 and 9, and 2 and 14 indicate that the more students learn new things during the project, the more they appreciate the importance of the project and its contribution to learning, and to their future role in industry. The strong correlations between questions 4 and 9 (and the correlations between questions 3 and 4) indicate that when students face new challenges in the project, they improve their independent learning capabilities. Also, the strong correlation between questions 4 and 8 and between questions 4 and 14 indicate that as the students feel more self-educated, they feel that the project prepares them better for industry.

The strong correlation between questions 5 and 8, which deal with understanding of the development process, shows that as the student learn more aspects of the development process, they improve their understanding of the process itself. The strong negative correlation between questions 5 and 10 means that as students learn more from the project, they feel that they use their time efficiently. The strong correlation between question 6, that deals with the guidance of the process, and question 7 which deals with the order and clarity in which consultation sessions are held, indicates that counseling meetings that are organized in an orderly fashion increase the satisfaction of the students. A strong correlation was also found between question 8 that deals with the contribution of the student to the understanding of the development process and question 14, which examines the student's perception of the project as a preparation for industry. The weak correlation between question 10, that considers the student's conception of a waste of time in the project, question 12 that considers short-term projects, and question 11 that deals with the student's sense of progress during the project, indicates that the perception of waste of time is not related to the length of the project nor to its structure.

Table 3

Spearman Correlation Coefficients

	Q	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	Correlation Coefficient	1.000	.357*	.607**	.357*	.457**	.480**	.447**	.709**	-.474**	-0.274	-0.269	-0.023	.573**	.450**
3	Correlation Coefficient	.357*	1.000	.512**	0.309	0.065	0.133	0.306	.383*	-0.275	-0.207	-0.248	0.038	0.301	.514**
4	Correlation Coefficient	.607**	.512**	1.000	.394*	.409**	0.304	.589**	.645**	-.485**	-0.165	-.481**	0.148	.583**	.350*
5	Correlation Coefficient	.357*	0.309	.394*	1.000	0.233	0.292	.641**	.383*	-.599**	-.424**	-0.166	-0.002	.454**	0.183
6	Correlation Coefficient	.457**	0.065	.409**	0.233	1.000	.746**	0.311	.344*	-.350*	-.323*	-0.282	-0.090	0.304	0.290
7	Correlation Coefficient	.480**	0.133	0.304	0.292	.746**	1.000	.496**	.374*	-0.270	-.464**	-0.225	0.019	.511**	.450**
8	Correlation Coefficient	.447**	0.306	.589**	.641**	0.311	.496**	1.000	.575**	-.579**	-0.255	-.400*	0.205	.637**	0.236
9	Correlation Coefficient	.709**	.383*	.645**	.383*	.344*	.374*	.575**	1.000	-.444**	-0.147	-.415**	0.191	.568**	.417**
10	Correlation Coefficient	-.474**	-0.275	-.485**	-.599**	-.350*	-0.270	-.579**	-.444**	1.000	0.262	0.222	-0.073	-.396*	-0.250
11	Correlation Coefficient	-0.274	-0.207	-0.165	-.424**	-.323*	-.464**	-0.255	-0.147	0.262	1.000	-0.006	-0.150	-0.055	-.386*
12	Correlation Coefficient	-0.269	-0.248	-.481**	-0.166	-0.282	-0.225	-.400*	-.415**	0.222	-0.006	1.000	-.328*	-0.136	-0.218
13	Correlation Coefficient	-0.023	0.038	0.148	-0.002	-0.090	0.019	0.205	0.191	-0.073	-0.150	-.328*	1.000	-0.046	-0.106
14	Correlation Coefficient	.573**	0.301	.583**	.454**	0.304	.511**	.637**	.568**	-.396*	-0.055	-0.136	-0.046	1.000	0.252
15	Correlation Coefficient	.450**	.514**	.350*	0.183	0.290	.450**	0.236	.417**	-0.250	-.386*	-0.218	-0.106	0.252	1.000

Other Results

There is a wide agreement among all stakeholders that the capstone project is different from any other course encountered by the students during their studies. About 90% of interviewees from academia emphasize the difference between the project and other courses. Most of these interviewees think that the capstone project must not only summarize the study period and examine what the students learned, but also teach them new things. *"It is basically the highest point a student has to reach, after he studied and now comes to implement his knowledge" (project advisor). "The goal is to get the student to deal with a problem he was not familiar with, based on what he learned in three years." (Dean).* About 78% of interviewees from industry and academia indicate the importance of the project for student's transition to industry. It is even used in industry as a tool for evaluation of potential candidates. *"In all the job interviews I did for young engineers - I asked them to bring their capstone project and asked questions about it. There you can test a real technical understanding of real life." (Engineer - CEO of a development company). "You must have the ability to expand what you've learned. The project is one of the first places that allows you this." (Dean).* Similarly, 82% of the students perceive the project as having high significance in preparing them for industry and hence "shapes" them and their professional "character". The project was found to have importance for the academic institution itself in other aspects:

- Contribution to students in the first years (1^{st}-3^{rd}) as a guideline for learning and understanding what is expected of graduates upon conclusion of their studies.
- A "concluding act" for the study program – serving as a landmark for students that marks their graduation.
- Developing a sense of efficacy and self-confidence in students who have not previously experienced project-based learning. *"Suddenly seeing that you are capable of putting up something so complex, and what you have learned is not just a theory. Especially with those of us who have not done such courses before... I felt I could do anything I wanted." (Graduate).*
- A tool for attracting potential candidates by "presenting students' abilities" upon graduation.

The study reveals that, in contrast to the transformations in this field due to Industry 4.0, the capstone project has not changed for decades. Some institutions have introduced specific changes but not comprehensively or as an "academic conception". In descriptions of the development process in all the interviews, no difference or change was observed in the structure or method of execution (beyond the project topics). *"The capstone project is done now exactly the same as it was 42 years ago when I was a student ... The world, perception and market have changed very much, and so fast. On the other hand, the way we teach has changed too little." (Dean).* Furthermore, the students usually are not familiar with other projects conducted in previous years at the same institution or in other institutions, even if they are addressing the same topic. The students rely mainly on basic internet searches, incidental personal familiarity, and information from their advisor.

In all academic institutions examined in this study, the development process of the project is the lengthiest, widest, and most extensive experienced by the students throughout their studies. However, there are no procedures from the policy makers of higher education regarding the structure or method aside from the number of credits. The institutions differ only in the emphasis on different aspects within the structure and “milestones”. Students are responsible for navigating among those milestones, with the advisor’s guidance. Some of the students even spoke of a “survival condition”, in which they put all their efforts into finishing the project successfully in order to avoid repeating their final year of studies. The study findings regarding the project’s process and milestone times produced no clear answer. About 30% of interviewees from academia claimed that the project time is too long. In contrast, about 40% claimed that the lengthy process facilitates real learning and deep experiencing that otherwise would not be possible. About 20% claimed that the time allocated for the project at present is appropriate and expressed no clear-cut opinion as to its length. It also emerged that 51% of the students felt that they were wasting time during the project, particularly regarding paperwork and dealing with bureaucracy. In addition, developing and working on the capstone project concurrent with other fourth-year courses was difficult for the students.

The relationship between academia and industry is an inseparable part of the discourse among all stakeholders involved. 82% of the students intend to work in industry after graduating, and about 85% of the students who are interested in graduate studies, wish to work in industry while studying. Industry representatives perceive new graduates as lacking suitability and abilities, and claim that employers must invest additional time in their training after graduation. Academia makes two conflicting claims – first, that even the 4 years devoted to a B.Sc. at present is insufficient for all the necessary tools. Second, some advocate shortening processes and shortening training within undergraduate studies to three years (Bentur, Zonnenshain, Nave, & Dayan, 2019). *"In order to achieve what an engineer needs, it is not certain that we have to do all the cumbersome way we have done so far" (Dean).*

The discussion on adjustments to the transition to industry and how to reduce the gap is common both to academia and to industry. The need for change is clear to everyone, as otherwise academic institutions and training processes might be irrelevant. The responsibility belongs to both. *"A private company knows that if it does not change it will not survive. It requires people to constantly examine what is happening around them." (Dean). "The tools and knowledge must be made relevant. Academia must in a sense guess what will be relevant and necessary in a few years" (Engineer, director of innovation and growth in a technology company).*

Although the students claimed that the project prepares them for work in industry, it must be noticed that this relates to the students' perceptions while still in academia. About 80% of the graduates said that the capstone project is not similar to the process in industry, and all industry personnel noted differences between the development process in industry and the parallel process in academia.
The main differences in the development process, found in the study, are:

Time of the Full Process

In industry, projects are carried out regularly and there is no uniform development time for all projects. The time of the development process is based on the complexity of the project, the team’s familiarity with production methods, etc. In contrast, in the capstone project the times are set and do not truly reflect actual development process times. No distinction is made between projects of different levels of complexity.

Times of the Stages within the Process

In industry, planning time follows the different stages of development and design reviews such as PDR/CDR (preliminary/ critical design review), where the process is motivated also by the need to rapidly reach results and to meet the schedule with its financial significance. Both academic and industry personnel agreed that in industry the time component is critical, while in academia it is sometimes possible to focus more on specific aspects. *"Our tendency is to shorten the process to get to the product. The nature of our calculations is in favor of the product itself, with the intention of getting a working product and not producing paperwork." (Engineer - CEO of a development company).*

Criteria for Assessing a Successful Project

While in both cases there is a physical product, in industry the emphasis is on the final product, mainly on its financial aspect. This is addressed both directly (profits from the product) and indirectly, by the product's contribution to the commercial firm. In contrast, in academia the definition of success is determined by the development process and the learning process. In most cases, the marketing dimension and contribution to reputation are not taken into consideration in academia.

Routine Work

In industry, a product development process is mostly part of routine work that includes several projects. Moreover, routine work is mostly carried out in teams that work on different components, and operate as part of a larger team. In contrast, in academia the capstone project is an outstanding event in the student's academic routine, and it is in fact the first time that the student contends with an extensive project, undertaking exclusive responsibility, unique demands, etc.

Delaying Factors

In industry, several delaying factors might affect the development process such as suppliers, production etc. In academia, delays stem mainly from logistics, paperwork and students' level of knowledge and technical ability, which sometimes requires rapid specialization in aspects of development that are not necessarily relevant to them.

Limitations

Despite the great importance of the study's findings and conclusions, this study has a number of limitations. First, the study deals only with physical products (durable goods), and does not deal with theoretical final projects and / or those that deal with hardware or research material and its properties. Second, the study was conducted at a specific academic institution (albeit with interviews at other institutions as well). Third, the questionnaire was distributed among students during the completion of the project itself, and students' perceptions of the project may need to be examined both before and after the project's completion.

Summary and Conclusions

The study described in this paper focuses on the capstone project in undergraduate mechanical engineering studies. The project serves both for evaluating students and a pedagogical tool, and is perceived by all stakeholders as an important tool. The study has shown that it has many gaps and shortcomings both as a pedagogical tool, and as a bridge between academic studies and professional life in industry. The project is considered by students as the most important and impactful course in the undergraduate program. However, despite its great importance, there are no precise criteria for project planning and learning outcomes. The study found that the most common aim of the project is still "to experience a process as in industry". No general obligatory definition of learning outcomes or pedagogical aim was found, and therefore it is up to each academic institution to determine its desired outcomes. There is a need for a change in the criteria for assessing a successful project, as well as clear definition of the capabilities to be achieved through the project. Fundamental revision and rethinking are required regarding the desirable parameters whilst simulating industry process, especially in light of the disparities presented in the study regarding development processes.

The project also serves as a marketing tool for the academia. It is necessary to examine projects' aim and topics as serving and contributing to the institution aim and goal, and to what the institution wants to "portray". This can lead to projects that can be used for marketing purposes, and create an ongoing situation of attracting more candidates. Efforts should be made to create an organized archive of all the institution's capstone projects. A mandatory requirement of finding similar projects must be integrated in the early stages. This can simulate a market research in industry, and create an opportunity for pushing the knowledge and abilities forward, by presenting innovative projects every year.

Even though the project is seemingly well-run and produces fine products, it suffers from insufficient dynamics. No different and innovative added value is obtained compared to projects carried out decades ago. The exact same project is done by different students for years. There is almost no change in the methodology, nor in the structure, nor in the outputs for generations. The milestones dictate the times of the project's development process identically for all participants, undifferentiated by the complexity of the project.

Considering the study findings and Industry 4.0 changes, it is necessary to update the project's process, generate added value, provide relevant outcomes, and verify that academia is alert and attentive to the changes in industry. The time distribution allocated for the project's milestones should be reconsidered. Academia must invest resources and embrace new and innovative methods of product development. Academia must ask itself why a project should be carried out for a whole year, and is it possible to achieve the desired result in a shorter period of time. This is supported by Bentur, Zonnenshain, Nave and Dayan (2019), who address the option of shortening the engineering program to three years, raising the significance of "academic time". This leads to the following two conclusions:

1. The qualities and capabilities we wish to teach the students should be conveyed in a quicker and more efficient method. This means that in addition to the acquired professional knowledge, we will also have to impart the essential skills and attributes in less time.
2. The students should be taught how to deal with time constraints. Not only from the aspect of time management, but also in their ability to solve complex problems, analyze information, think creatively, reach products in a short span of time, etc.

Academia has a unique opportunity to utilize the project to help bridge some of the gaps between academia and industry and to arouse the students' curiosity. This is also corroborated by Núñez et al. (2017), who note that the project purpose is to increase students' learning outcomes. Hence, it must be utilized to impart the most important and significant skills (such as independent learning, ability to adjust to change, multidisciplinarity, and more), mainly those that are not imparted in other courses. Therefore, it is also important that students engage in PBL at least once during their studies before carrying out the capstone.

A number of points emerged that shed new light on students' perceptions. Despite the large load and other courses being done in parallel, the more the students face new challenges they are unfamiliar with, the more they attach importance to the project. It was also found that the more independently students learn in a project, the more they feel they understand the development process, and accordingly also feel that the project prepares them for industry.

In conclusion, the capstone project is not being conducted optimally for all stakeholders. Academia must consider modifying the project to use it as a better pedagogical tool in the age of Industry 4.0. Academia must not only convey knowledge but also adjust the way it is conveyed according to the changing environment. This will give graduates innovative and relevant abilities, help reduce the gaps between academia and industry, and can lead to a rise in satisfaction with the institution and with studies in general.

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Appendix

Questionnaire Regarding the Capstone Project

In order to improve the learning process in the capstone project, we ask for your opinion on the project you are currently carrying out (the survey lasts about 2 minutes).

Please answer the questions before you, we'll be happy if you attach your comments, thanks for the cooperation!

* The survey is anonymous, and the use of data is for research purposes only.

1. What is your goal at graduation? *

- ☐ Work in industry
- ☐ Continuation of studies - Master's degree
- ☐ Not interested in working in the field
- ☐ Other

2. To what extent does learning in the capstone project contribute to you compared to learning in other courses that you took during the degree? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

3. To what extent do you learn new things during the capstone project? *

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	To a very large extent

4. To what extent does your independent learning improve during the project? *

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	To a very large extent

5. To what extent do you learn about other aspects of product development during the project (user, financial aspects, marketing)? *

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	To a very large extent

6. To what extent does project guidance contribute to the development process? *

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	To a very large extent

Please detail (deficiencies, conservation / improvement)

7. To what extent are the counseling sessions held in an orderly and clear manner? *

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	To a very large extent

Please detail (deficiencies, conservation / improvement)

8. To what extent do you feel that the capstone project helps you understand what a development process is? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

Please detail (deficiencies, conservation / improvement)

9. To what extent does the project allow you to face challenges you did not know? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

10. To what extent did you feel during the project that you were wasting time? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

On what topics?

11. To what extent during the project did you feel that you were "lost" and did not know how to proceed? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

On what topics?

12. To what extent do you think the project time should be shortened? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

13. To what extent would you like industry to be involved in the project? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

14. To what extent do you think the project prepares you for a job in industry? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

15. If the capstone project was defined as an elective course, to what extent would you recommend another student to take the course? *

	1	2	3	4	5	
Not at all	○	○	○	○	○	To a very large extent

Do you have any comments / insights regarding the capstone project?

General information

Gender

- ☐ male
- ☐ female

Age

Academic institution

- ☐ college
- ☐ university

Department and track

- ☐ Mechanical Engineering - Mechatronics
- ☐ Mechanical Engineering - Product Development and Design
- ☐ Mechanical Engineering - Natural Gas
- ☐ Other: ______

Submit

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