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Student perceptions of the societal linkages of engineering innovation

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1. Introduction

Innovation is one of the core elements of engineering organizations striving for economic success. While there are well-established practices and processes used in engineering design and innovation work, engineering innovation is also affected by a multitude of external factors in the business environment. These local and global factors and practices [1,2] represent contextual societal factors, and they may both limit and enable innovation [1,3,4]. Such factors lay a foundation for how organizations can operate and what kind of frames they need to utilize in their development efforts. On the other hand, increasing emphasis is being placed on not only how society shapes engineering, but the role engineering plays in addressing societal and sustainability challenges [5,6,7]. Engineers can play an active role in championing change and sustainable solutions, whether as entrepreneurs or intrapreneurs [8]. However, many questions remain in understanding when and how engineers perceive such societal influences and opportunities.

One lens through which to examine societal factors and their linkages to engineering innovation efforts is the PESTEL-framework, which has traditionally been used as a strategic planning tool to analyze political, economic, social, technological, environmental and legal opportunities and threats in business environments. The framework draws from Aguilar's concept of an ETPS (economic, technical, political, and social) analysis [9], and was expanded to STEPE, and later PESTEL [10,11]. This framework, often referred to as a macro-environment analysis [12], is used to analyze and identify possible opportunities and threats, categorizing them into political, economic, social, technological, environmental and legal influences [13]. It is a tool that can and has been used to understand the context of a variety of engineering design problems. In the construction and building industry, for example, the PESTEL framework has been used to improve strategy and to identify risks in a variety of projects [14,15,16], while in the automobile industry the framework has been recognized as a useful tool particularly for identifying emerging trends [17,18]. A recent study has also used the framework to identify dimensions for sustainably managing the healthcare waste caused by COVID-19 [19]. Through analyzing external factors in organizations' operating environments, the PESTEL framework can help structure evaluation of dynamics, competition, and market position, enabling innovations and re-engineering [20].

Despite growing attention to sustainability and social responsibility, societal and external factors continue to receive little attention in engineering education compared to internal, company or team originating challenges and enablers [2]. The definition of contextual factors is often fuzzy and varies depending on the area of study [21], and the factors included in such considerations vary from study to study [22,23,24]. Nevertheless, multiple studies have demonstrated the influence of *political factors* (P) such as stability and policies [4,12,23,25], and *economic factors* (E), such as economic cycles, growth and production costs [12,25], on pursuing engineering opportunities. While *social factors* (S) have received less attention, a growing number of studies have explored how quality of life, cultural considerations and social trends can give rise to new challenges and opportunities [12,23,25]. *Technological factors* (T), in turn, are often more readily identified by engineers, considering not only the technological aspects of the specific solutions they are working with, but the implications of more overarching developments such as digitalization and artificial intelligence [28]. For example, new developments in opportunities in virtual prototyping can decrease development cycles and cost, opening up new opportunities to explore [26]. *Environmental factors* (E), such as environmental sustainability [25], circular economy [29], and controlling or preventing pollution, waste and climate change [12] can also all either pose challenges or enable new markets and engineering opportunities. Finally, *legal factors* (L), such as regulations and patents can restrict operations or drive increasing demand for new engineering solutions [1,12, 30].

Yet while there is abundant literature on the challenges and opportunities that this range of societal factors introduce into engineering, little is known about the degree to which and mechanisms through which engineers take such considerations into account in practice. Engineering innovation often tackles ill-structured issues, where considerable expertise is needed to arrive at a fruitful “frame” of the issue - i.e. what features and data is meaningful and pertinent to the issue and what is irrelevant and “background noise” [31,32,33,34]. What type of frame is adopted influences what kind of solution opportunities are sought [35]. Yet past research has demonstrated that engineering experts are more likely than novices to develop more nuanced frames, note more interconnections, and approach information more critically [36,37,38]. Educating engineering students in ‘strong disciplinary paradigms’ may contribute to a decrease in their engagment in societally oriented domains, however, a focus on stragetic competences may encourge students to engage with sustainable solutions [39]. As such, engineering skill can be expected to play a role in determining the degree to which societal factors influencing engineering opportunities can be noted. Despite growing efforts in incorporating sustainability to engineering curricula, we know little of the type and extent to which engineering students recognize societal factors in engineering innovation. The current study begins to address this gap by examining how graduate engineering students recognize societal influences on and by engineering innovation opportunities in different industries.

2. Methodology

The present study examines how master’s level students, having already completed a bachelor’s degree in engineering, identify, understand, and perceive different types of impact and influences on engineering innovation. Specifically, we examine student perceptions on political, economic, social, technological, environmental, and legal (PESTEL) connections of four real-world engineering innovation cases.

2.1 Study context and cases

Data was collected in a master’s level course for mechanical engineering at Aalto University. Representative of the mechanical engineering student population of the institution, the majority of students on the course were Finnish White males and had completed a bachelor’s degree in engineering. During the first weeks of the course, which focuses on mechanical engineering in society, students could choose to work on one of four Finnish engineering case studies. Each case was constructed using data from interviews with two company representative engineers who had worked on the case products.

All four cases discussed the development of physical business-to-business products available on the market at the time of the course. One of the cases described the development of an air quality detection device designed to be implemented in kitchen appliances, and another case was built around the development of a construction site dust remover. The third case described the development of an AI aided recycling robot aimed at waste management markets, and the last case discussed the development of a new type of paper machine for the pulp and paper industry. The case descriptions included the need for which the device was developed, a description of the novel or valuable features in the product, as well as a storyline of the development process with some enabling and challenging factors. The cases were all similar in length, roughly three pages long, and included pictures from the project and of the product.

2.2 Data collection and analysis

The data used in this study was collected from 115 student responses to an assignment where they were given an individual task to “reflect on three out of the six PESTEL dimensions" of their chosen case. The students had been given the task after being introduced to the PESTEL dimentions in class. They were requested to make at least two justified connections per dimension. Students could freely choose which three dimensions they wished to reflect on.

Table 1. An example of the analysis.

Student’s answer (segment)	PESTEL dimension	Subtheme	Valence	Direction of influence
"Due to breathing in dusty air, it is natural that construction workers would want to take frequent breaks in order to catch their breath. This definitely slows down the pace of construction leading to additional costs due to unforeseen delays. However, an investment in this device can contribute to [a] faster pace of work completion. This will have a net positive economic impact"	Economic	Client interests	Positive	Influence on case
"From technological point of view one large thing that impacts this is how often people need to change their [kitchen appliance]. Obviously this is not a product that people change for fun and its changed more in a need basis. Therefore the fact if new technology does not have clear difference to the old devices will most likely mean that only the people who have to change their [kitchen appliance]are going to be the realistic customers. Advantage however for [company’s] case is that it transforms the [kitchen appliance] to somewhat different product from original instead improving it.”	Technological	New technology	Negative	Influence on case

The students' assignments were collected and responses were segmented so that each reported connection was contained in a separate proposition [40]. These segments were first categorized based on the PESTEL connections the students had identified in a top-down manner, grouping for example all political connections together (an example of categorization is presented in Table 1, above). Then, each segment was grouped together into semantic-level subgroups in a thematic analysis to identify salient themes within these societal factors [41]. Finally, each segment was categorized to note the perceived valence of the connection (positive, negative, or neutral, as depicted by the student) and the direction of the observed connection (influence on the case, by the case or both, as indicated by the student). No instances of bidirectional influence were observed in the data, and in six segments, the direction was unclear and was not assigned.

3. Results

Altogether, the students reported 794 political, economic, societal, technological, environmental, and legal connections relative to the four innovation cases. The prominence of connections relating to each PESTEL dimension varied (Table 2). Technological impact was the most frequently considered dimensions (n=236 connections were identified). This was followed by environmental factors (n=186) and economic factors (n=131). As students were required to discuss only three dimensions of their choice of the six PESTEL dimensions in their assignment, this suggests technological, economical and environmental factors were preferred choices. Societal (n=96), political (n=85) and legal (n=60) were somewhat less frequently chosen for consideration.

Table 2. The PESTEL dimension and frequency of associated subcategories among student identified connections

PESTEL dimension	**Subthemes**	**Valence of identified connection**			**Total**
		Negative	**Neutral**	**Positive**	
Technological (236)	Automation	13	9	62	**84**
	Technology development	20	9	53	**82**
	Design and implementation	4	2	22	**28**
	Operating environment	9	2	2	**13**
	Product usability	4	2	3	**9**
	Other technological factors (e.g. interdisciplinarity, data security, cost of technology, components, leveraging exisiting solutions)	6	1	13	**20**

PESTEL dimension (cont.)	Subthemes (cont.)	Valence of identified connection			Total
		Negative	Neutral	Positive	
Environmental (186)	Recycling	3	0	52	**55**
	Conserving nature	10	1	35	**46**
	Clean air	5	1	20	**26**
	Energy consumption	11	1	8	**20**
	Overall sustainability of the solution	5	0	12	**17**
	Other environmental factors (e.g. climate change, waste disposal, geographical location)	5	1	16	**22**
Economic (131)	Local economy	4	3	22	**29**
	Client interests and demand	1	0	28	**29**
	Business profitability	16	1	11	**28**
	Product costs	12	1	1	**14**
	Market area and competition	3	1	8	**12**
	Other economic factors (e.g. workforce, global economy, resources)	12	0	7	**19**
Societal (96)	Health and safety	0	1	41	**42**
	Societal attitudes	3	0	16	**19**
	Employment	5	0	7	**12**
	Other societal factors (e.g. quality of living, client attitudes, societal structure differences)	9	0	14	**23**
Political (85)	Local political strategy	8	5	14	**27**
	Legislation decisions	8	2	9	**19**
	Global politics	5	1	7	**13**
	Environmental policy	1	1	8	**10**
	Other political factors (e.g. regulation- deregulation, political stability, spreading awareness)	4	5	7	**16**
Legal (60)	Health and safety law	4	0	14	**18**
	Legislation changes	5	0	5	**10**
	Country-specific legislation	8	0	1	**9**
	Other legal factors (e.g. IPR protection, common standards)	12	4	7	**23**
Total		**214**	**54**	**526**	**794**

The direction of influence of the observed connections (Table 3) was mainly noted as being *on* the case. Students were able to identify more negative factors that would impact the selected cases than instances of the cases influencing society (negative influence on case n=194, negative influence by case n=21). For neutral influence the influence on cases was n=1 while the neutral influence on cases was n=69. Where positive influence was identified, students noted both connections influenced by the case (n=227), as well as on the case (n=296). They were able to identify connections of how the case would influence society, as well as how societal issues influenced the case.

Table 3. Direction of perceived influence of PESTEL connections

Dimension	**Influence on case**			**Influence by case**		
	positive	**negative**	**neutral**	**positive**	**negative**	**neutral**
Technological	130	56	24	25	0	0
Environmental	26	29	4	117	10	0
Economic	44	42	4	31	6	1
Societal	30	14	1	48	3	0
Political	39	25	14	6	1	0
Legal	27	28	2	0	1	0
Total*	*296*	*194*	*49*	*227*	*21*	*1*

*Table and totals exluding six non-directional segments in the data set of 794 segments

3.1 Technological impact

The majority of the identified technology connections were seen as positive (n=155). Positive considerations were commonly identified as influencing the cases (n=130) and in negative considerations, the focus was entirely on influence on the cases, rather than effects created by the engineering solutions. Approximately a fourth of the technological considerations (n=56) were about negative influence on the cases. The development and use of new technology posed challenges from which one common was related to keeping up with the constantly developing technology around the cases.

> *"The world of technology is progressing day and night. To keep with the technological advancements in different areas of the product, and to keep ahead of the competitors, the company must have a department working in research and development to improve the product and keep it updated according to the latest trends such as Artificial Intelligence, Machine Learning etc."*

Automation was the most frequent technological connection identified from the student answers (n=84). New technological tools were seen to enable improved product operations, less faults and quicker and more accurate product performance. From these, almost all (n=58) were directly influencing the cases. For example, artificial intelligence and machine learning algorithms were seen to open up new opportunities through automating functions in the engineering solutions.

> "*[The case product's] the most important technological aspect is the automation, which is controlled by artificial intelligence. With AI the robot can be working without the constant need of a supervisor and that way makes [its main function more efficient] and very automated.*"

Technology development in general was the second most common technological factor identified in the student answers (n=82). This included connections to technology development, new technology, innovation, research and digitalization. The majority of the answers were linked to positive connections (n=53). One frequently noted connection was that new technology, developed as part of the product case, enabled solving issues which could have not been solved with prior technological solutions.

Design and implementation connections were typically positive (n=22), noting various design process and decision benefits of the developed engineering solutions: being able to leverage technical knowledge within the case company for efficient development, flexibility and control afforded by within-company developed solutions, and superior mechanical design, material selection, and modularity. In addition to these more prominent connections, a few students also noted challenges caused by the operating environment, such as difficulties in integrating the case engineering solution to other devices, as well as concerns in product usability and product component availability.

3.2 Environmental impact

Environmental impact was the second most commonly evaluated factor (n=186). These connections were mainly positive (n=143, compared to n=39 negative connections and n=4 neutral). In contrast to the technological factors, most positive connections here were seen to be created by the solutions (n=117), rather than representing environmental factors influencing the development of the solutions.

Recycling was the most common environmental factor (n=55). Almost all of the recycling connections were positive (n=52), and seen as a positive impact enabled by the case solutions. For example, the engineering solutions were seen to automate recycling processes and promote circular economy principles. Similarly, the solutions enabled creating less waste through increasing the amount of recycling and reducing the amount of generated waste with lower material requirements for products which they produce.

> *"With the amount of mixed waste created everyday an effective machine to sort out the recyclable material will have a great impact on the size of the landfills, freeing up space and lessening the pollution of the environment."*

Conserving nature was another common environmental factor (n=46). Students noted the enabling effect the cases had on saving natural resources and decreasing pollution through reducing waste. The only negative impact of the cases reported in relation to conserving nature was the use of plastic materials, recognized to produce pollution.

Other identified environmental connections included *clean air* (n=26), seen as being influenced positively by the cases by cleaning air and reducing emissions, and *energy consumption* (n=20), seen as both a challenge on the cases and a positive impact by them. The challenge came from the required energy that the case products needed to function, and positive impact from the advanced products requiring less energy. O*verall sustainability* of the solution (n=17) was considered to have a positive influence on their surroundings by slowing down climate change through a smaller carbon footprint.

3.3 Economic impact

Economic impact was the third most common PESTEL dimension in the student answers (n=131). Though most connections were again positive, the split between positive and negative connections (n=77 and n=48, respectively) was more even than in technological and environmental considerations. *Local economy* was seen strongly as a positive impact on the cases (n=22 out of 29 connections), beneficial to economic growth and getting funding.

> *"Finland's national economy is also impacted, since the case company is a Finnish company and has long been a leader in its industry. With an improved position in the market [by the success of the case product in question], Finland's national economy has only improved."*

Economic growth was argued to be accelerated by the cases. In a reciprocal manner, the need for economic growth was also seen as enabling the development of the case products as a way to answer growing demand. The ability to satisfy or meet precisely clients' interests with product requirements and lower costs was seen to enable success (*client interests and demand,* n=29). The need to find a suitable price point, in turn, relates to *business profitability* (n=28). Negative effects noted included required company investments, limited market area and challenging sales environments. Product price was identified as the main economic challenge in relation to the cases. Finding the optimal price for the product was argued to be challenging, requiring finding a price low enough to ensure sales, but high enough to get profit.

Other identified economic factors noted included, for example, *product costs* (n=14), such as difficulties in balancing costs in installation, manufacturing, maintenance and development when the budget is limited. *Market area and competition* (n=12), were seen as positive, noting that the case products increased the competitiveness of the case companies. A negative impact of competition was identified in the high level of competition within the market. Exchange rates and industry norms were also seen as challenges influencing the overall competitive advantage of organizations.

3.4 Social impact

Most social connections (n=96) were labeled as having a positive influence. The most common societal connections were *health and safety* related (n=42). With one exception, all of the connections were seen to have a positive influence. Most of the mentions (n=35) determined the cases to have influence on the surroundings, including the highest number of connections to health factors and safety factors. Commonly the mentions identified the positive impact of the cases in improving general health and safety with advanced solutions:

> *"Society is composed of people. Their individual wellness impacts society directly. The use of this machine helps people to improve their health as it [cleans air]. In this way, workers can see improvements in their health, which is beneficial for their individual lives, for the society as a whole, and for [their employer] for having less ill workers."*

Considerations connected to occupational health and safety were found in several instances, including preventing people from working close to hazardous machines or in a dirty environment.

Societal attitudes was the second most common social impact identified by the students (n=19). This factor included connections to societal attitudes, cultural norms and cultural trends. For example, students noted attitudes that motivate people to use the case products and therefore have an enabling impact on the cases. These motives were often tied also to the environmental dimension, such as climate change. Similarly, *employement* (n=12) cosiderations were closely tied to economic workforce considerations. These connections speak to the interconnectedness of the PESTEL framework dimensions.

Less common societal factors identified by the students included *quality of living, client attitudes* and *society structure differences*. Quality of living was seen to have a positive impact on people's quality of life and lifestyles. Other societal connections were made through highlighting population growth and education levels. Higher education was seen to have the potential to support the use of technologically advanced case products, and lower levels were connected to employment types that may be made redundant by the products.

3.5 Political impact

Political impact was a less often considered dimension (n=85), and approximately half of these connections (n=45) were considered positive. *Local political strategy* was the most commonly referred to political influence (n=27), including, for example, tax policy, the Finnish political image and politics influences funding opportunities. These were also tied to economic impacts (in terms of the outcomes of funding opportunities) and environmental impact:

> *"Overall the environmental issues [which the case product is solving] are very much present in today's politics. [...] political awareness for the need for actions to prevent and/or slow the climate is growing. With [a specific environmental topic] as one of the important political topics [the case company and their case product] is at the front line.*

> *It presents solutions to a very topical issue. [This has potential to get increased support from the local politicians.]"*

Indeed, *environmental policy* (n=10) was considered mainly as a positive influence on the cases. Voting attitudes were considered to be enabling political connection as climate activism is increasingly trending among those who are in the voting age and their voting attitudes might increase the demand for one of the case products. *Legislation decisions* (n=19), in turn, included observations of connections to various laws that influence product development including health and safety, employment, data protection and decision-making related to import and export restrictions.

Global politics (n=13) included connections that refer to EU and foreign politics. Changes in the political arenas outside Finland were seen as challenging if they were to limit the demand for the case products, and enabling if they supported the case companies. EU policies and the stability of the European Union was seen as a positive influence on cases. Other connections noted under the political impact dimension (n=16) were *regulation and deregulation, political stability* and *spreading awareness.*

3.6 Legal impact

Legal impact was least commonly considered (n=60). Here, *health and safety laws* were the most frequently noted (n=18), typically seen as positive influences on the engineering innovation cases. For example, the case could be seen to benefit from the health and safety laws, as the legislation supports the cases' missions and potentially increases demand for the product:

> *"Laws on the safety conditions of work environments might play in this case product's favour. If the working conditions in [the client industry] are too dangerous for humans, [and the laws related to these conditions are tightened, products such as the case products in question] have to be used. It might increase demand."*

Various laws, levels of legislation as well as *legislative changes* (n=10) and *country-specific legislation* (n=9) were considered in student responses and include environmental law, data protection law, labor law and consumer protection law, and additionally the level of legislation in general. Enabling legal influences supported product development while negative country-specific legislation and chenges could have cost implications or additional regulations. For example, students noted increased demand as a positive influence of country-specific legislation if the country has mandatory recycling or environmental initiatives. Other legal considerations included *IPR protection* and *common standards*. Data protection law was identified as a possible challenge:

> *"The product consists of multiple sensors collecting and saving data. Because of this, naturally the question about data safety and GDPR is essential. Who has access to the data, what can be made with it, what if it gets to the wrong people?"*

4. Discussion

Examining four engineering innovation cases in business-to-business markets, the current study set out to examine what type of societal connections graduate level engineering students notice in developing new solutions. The results reveal a propensity to focus on positive rather than negative connections (523 vs 215 identified connections). Similarly, students were more likely to note how societal factors influenced the engineering cases, rather than how the cases themselves had an impact on such factors (with 539 vs 249 connections). Given the opportunity to reflect on three PESTEL dimensions of their choice, most students chose to examine technological and environmental factors, followed by economic connections. Societal, political and legal factors were less commonly examined, and additional research is required to establish whether this was due to interest, ease or other factors.

Nearly all students (102 out of 115) reflected on the role of technological context in the engineering cases. While this focus is perhaps unsurprising, it is interesting that the clear majority of the noted connections reflected how technological trends, advancements and state influenced the engineering solution development efforts (210 out of 236 connections), rather than how these solutions might advance technology. Technological considerations were also the only dimension where not a single student identified a negative or neutral effect that the cases might have on technology. This lack of criticality may suggest students adhering to a worldview that positions technology as a general positive enabler, although the current study provides limited insights as to why such an omission occurred. Indeed, previous studies have found engineering experts more likely to approach information critically [36], suggesting additional prompting might be required for engineering students to expand consideration into negative effects.

Similar to previous studies on responsible innovation opportunities in engineering, environmental factors seemed to be most prominent in societal connections other than technological context [42]. Environmental considerations were the only dimension where influences by the case clearly outweighed influences on the cases. Indeed, positive environmental effects brought by the cases, such as reducing waste and resource consumption, represented half of all positive influences noted by the cases. As such, while economic elements have dominated decision-making in business [43], the data suggests a certain interest or ability amongst engineering students to supplement such considerations with environmental sustainability. However, reporting negative influences caused by the cases was rare (with just ten mentions), and students were more likely to note environmental challenges than opportunities. As such, it is not clear to what degree environmental impact would be a driving factor for development.

Considerations related to society tended to focus directly on people, such as their culture, demographics, age, level of education and overall health and wellness. Here, students focused on the positive impact that the cases had had or could have, such as improving user safety, as well as enablers for their development, such as increasing health awareness driving demand for new engineering solutions. In contrast, political and legal connections were more often connected to the surrounding systems and structures. Similar to technological considerations, political and legal factors were most frequently noted as influences on engineering development cases, however, the noted connections were fairly equally split between enabling and hindering factors to take into consideration. While some of these connections reflected very specific regulation and legislation, most perceived connections were related to fairly general areas of legislation, policy and political climate, suggesting somewhat less clear perceptions of interconnectivity than for example in technological and environmental factors. This could also be seen in many societal connections, suggesting more support may be needed to develop engineering "literacy" in examining societal, political and legal factors [39]. Previous studies have also noted engineering students and novices are less likely to spot interconnections with problem framing [38] and less likely prioritize information needs [27], [37], however, the current study did not allow systematic comparison across the intersections of different dimensions.

Similarly, while students noted economic factors fairly frequently, these were often rather broad themes related to overall competitiveness and growth. Manufacturing costs and pricing was considered in more detail, and students were more likely to note both economic enablers and challenges than in many other dimensions. Influences by the cases on economic factors tended to be product and company specific, rather than examining broader economic implications. As such, similar to societal, political and legal factors, the results suggest some difficulty in identifying both specific mechanisms of influence as well as limited consideration of the broader economic influence on engineering solutions. Recent studies have called for an exploration of student's motivation to participate and engage with engineering entrepreneurial education [44] and economic content [45]. These have been identified to support complex problem solving within engineering, allowing for the exploration of multiple possible solutions instead of a single, often predictable technical solution [46]. This supports the notion that engineers, as entrepreneurs or intrapreneurs [8] can contribute to innnovative sustainable solutions.

Taken together, while engineering development may be initiated in response to societal needs or changes [25], the fairly infrequent observations of forward-looking new societal opportunities or potential impact that the engineering cases could have is suggestive of limited focus on engineering agency amongst the students. As such, it is not clear how easy it would be to proactively pursue engineering opportunities. Furthermore, the results suggest there remains limited awareness of what these opportunities might be in the first place, with many dimensions of societal connections being noted on fairly general levels. Environmental impact stands out here as a more specific, more impact oriented dimension, but even here, students were unlikely to identify potential negative influences that the solutions could have. While frameworks such as PESTEL can be helpful in broadening the scope of factors considered, such frameworks need to be supplemented with sufficient knowledge on these factors, or connections to others with sufficient knowledge, in order to be able to address and leverage such factors within engineering solutions. As organisation will expect future engineering graduates, as well as graduates from other disciplines, to create value and innovate within their positions, the skills required to explore these contexts are essential [46]. Furthermore, the results highlight the need to further support examining potential adverse effects of engineering innovation, broadening the scope of considerations from intentional design targets to possible unintentional effects. Throughout all dimensions examined by the students, noting any adverse effects of the solutions was rare.

5. Conclusion

The study revealed that students could identify a variety of societal influences on and by engineering development cases when prompted by the PESTEL framework. The students did not receive explicit training on using the PESTEL framework beyond its introduction, but managed to note several factors in the complex interplay of political, economic, social, technological, environmental and legal dimensions. As such, the results affirm that even relatively minor interventions can help to begin introducing a broader array of societal considerations into engineering coursework. As educators increasingly work to incorporate sustainability into curricula, all levels of interventions can support one another. In addition to acting as miniature interventions, frameworks such as PESTEL can also be used as a curriculum review tool to reveal students' current ability to conceptualize connections and identify areas that require additional coverage or discussion to support effective prioritization in limited class time. However, as the current study is based on a single course, more research is required to explore effective ways to use such tools as a diagnostic element within a curriculum and teaching and learning context.

At the same time, the current results also showcase how merely introducing the PESTEL framework led to student reflections that mainly identified societal influences *on* the cases, with possible effects of the engineering solutions on society less apparent and prominent in student considerations. In particular, students were likely to overlook potential negative effects that the engineering solutions might have. While further research is required to examine the connections between student perceptions and subsequent intentions and behaviors in developing engineering solutions, overlooking opportunities to act and influence societal factors suggest engineering education might be well served by combining sustainability efforts with entrepreneurial training to aid proactively identifying and addressing opportunities. Further studies could explore effective combinations of training in opportunity recognition, domain knowledge of societal factors and problem framing and solving frameworks. Better understanding of how students frame engineering development issues can pave the way for learning to develop more holistically sustainable solutions in engineering.

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