Engineering educators' perspectives on the feasibility of fostering sustainability through the internet of things

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Abstract: The purpose of this study was to identify the feasibility of integrating the internet of things (IoT) in engineering education (EE) to promote environmental, social and economic sustainability. This purpose is explored through self-report surveys with 113 engineering educators in Thailand. Analysis relied on descriptive statistics and two-way ANOVA. Results revealed high feasibility of integration with less feasibility for social sustainability. There were no significant differences in relation to feasibility and demographic factors such as educators' years of experience and type of EE. Respondents identified factors that can promote the integration. These were grouped into the following categories: curricula and programs, instructor and student-related factors, administrative and policy factors and technology-related factors.

Keywords: engineering education; project and problem-based learning; smart; engineering educators; social-environmental-economic sustainability; internet of things; IoT.

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1 Introduction

The internet of things (IoT) is a complex socio-technical system and disruptive innovation with the potential to introduce profound societal changes for consumers, industry and the public space (RAE, 2018a). These societal changes are particularly relevant for sustainability. In fact, the IoT could be a 'game-changer' for sustainability (Arias et al., 2018). Sustainability can be understood in terms of three pillars of environmental, social and economic sustainability (see Purvis et al., 2019) as well as in terms of how it is articulated in the United Nations' 2030 Agenda for Sustainable Development and its accompanying 17 sustainable development goals (SDGs) (see United Nations, 2015). The goals focus on elimination of hunger and poverty and on ensuring access to education, sanitation, clean water, affordable energy, and decent work. The SDGs also promote good health and well-being, inclusion, equity, equality and resilience. They emphasise sustainable, resilient infrastructure, safe and peaceful communities, climate action, and sustainable life on land and in the oceans. The 17 SDGs do not only include goals related to the environment (SDGs 6, 7, 12–15) but those related to society (4, 5, 10, 11, 16, 17) and the economy (1, 2, 3, 8, 9) (Wu et al., 2018). The 17 SDGs can also be categorised as follows: people (1–5), planet (6, 7, 9, 11–15), prosperity (8), peace (10, 16) and partnerships (17) (Wu et al., 2018).

The IoT can directly address five of the United Nations' 17 SDGs: industry, innovation, and infrastructure, smart cities and communities, affordable and clean energy, good health and well-being, and responsible production and consumption (Arias et al., 2018). For example, in terms of the environment, Rausser et al. (2017) described how a Smart Grid Project in Ireland helped fulfil commitments to a low-carbon future. The Government of Canada's Smart Building Initiative (see https://www.tpsgc-pwgsc.gc.ca/biens-property/intelligents-smart/index-eng.html) collects and analyses data from devices in buildings to identify where equipment is being used inefficiently or where systems are wasting energy. Smart environments can help meet needs related to challenges of sustainability including social needs (Moreno et al., 2015). Smart cities are "a powerful driving force for socio-economic change … and a driver of innovation" [Cathelat, (2019), p.44]. They can help alleviate or eliminate problems caused by mass urbanisation including those related to "water security, sanitation, urban violence, inequality, discrimination, pollution, [and] unemployment" (UNESCO, 2019).

1.1 Affordances and constraints of IoT for sustainability

The World Economic Forum (2018) reported that 84% of IoT projects analysed addressed or potentially addressed the SDGs. However, the forum concluded that there is limited awareness of the link between IoT and sustainable development. Likewise, there has been limited awareness of how best to educate engineering students to maximise the affordances and minimise the constraints of IoT for sustainability. The focus on affordances is in recognition of the fact that although IoT has the potential to promote sustainability, for example, through smart cities, smart manufacturing, etc., it does not automatically promote sustainability. In fact, IoT can actually constrain and inhibit sustainability. As Volkoff and Strong (2017, p.1) explained, "affordances arise from the relation between the technology and the actor", i.e., e-mail affords the possibility of communicating. This perspective goes beyond thinking in terms of advantages, value or benefits of a given tool. Instead, it focuses attention on what the tool can potentially (though not necessarily or automatically) make possible. As a hypothetical example, application of IoT in a smart factory environment offers the possibility of resource efficiencies by automating production through reliance on robots. However, these resource efficiencies do not automatically promote sustainability. The reliance on robots can result in higher electricity consumption as well as job losses. Thus, in that case, sustainability is constrained as opposed to promoted. This perspective on the affordances of technology highlights the fact that IoT and smart technologies/environments are merely *possible* game changers for sustainability. Not only must the affordances be maximised, but the constraints must be minimised. Table 1 outlines some examples of the potential affordances of IoT for sustainability.

Individuals can exercise agency to maximise the affordances. However, constraints, like challenges, may limit the affordances when actors use technology. Souter and MacLean (2012) highlighted the environmental damage caused by the production of technologies such as computers and phones. They noted that their production is carbon-intensive and relies on the mining of scarce resources that can have negative social, political and environmental effects. Furthermore, their disposal results in e-waste. Reliance on batteries to power billions of devices could result in environmental harm depending on how the batteries are disposed of (RAE, 2018a). Billions of internet-connected devices and the subsequent 'tsunami of data' "could consume one fifth of global electricity by 2025 and contribute to CO_2 emissions" (Vidal, 2017). Waibela et al. (2017) predicted that the manufacturing of smart devices will have an overall negative effect on the environment.

From a social and economic perspective, increased automatisation of production can result in 'major job losses' with subsequent social challenges particularly in industrialising countries (Beier et al., 2017). IoT will result in massive amounts of data that will only be meaningful when the data have been effectively analysed, understood (Xu et al., 2014), and in this context, interpreted in relation to sustainability. The collection of data also poses threats related to privacy and safety (RAE, 2018a). Cloud storage of data may result in breaches of security (Waibela et al., 2017). The development of the IoT means the attack surface is larger which means that there is a greater threat to cyber-resilience (RAE, 2018b). Safety and security might be directly compromised through the introduction, for example, of malware in healthcare and consumer applications, in autonomous vehicles or in personal surveillance systems (RAE, 2018a). Other constraints and affordances have been outlined by Xu et al. (2014).

Table 1 Examples of potential affordances of IoT for sustainability

Application	*Affordance*	*Source*	*SDG*
Smart farming: sensor drones coordinated with irrigation systems	Target hunger and poverty	De Clercq et al. (2018)	1, 2
Smart mining: sensors in mines and on miners	Promote safety good health and well-being	Xu et al. (2014)	3
Cloud computing	Promote access to educational infrastructure	Patra and Das (2013)	4
Blockchain technology	Address barriers to women's financial inclusion and economic empowerment	Niforos (2017)	5
Automated meter reading and big data	Optimise water system performance and supply	Koo et al. (2015)	6
Digitalised industrial production	Resource and energy efficiency	Beier et al. (2018)	7
Smart industry	Human resource opportunities	Kiel et al. (2017)	8
Smart concrete using a distributed sensor network	Detect underground stress before earthquakes	Nihalani et al. (2019)	9
Wearable devices	Inclusion of disabled (e.g., blind, hearing impaired)	Polonetsky and Gray (2017)	10
RFID tags and GPS	Promote accessibility in smart cities	Mora et al. (2017)	11
Big data and predictive analytics	Collaborative performance for sustainable production and consumption	Dubey et al. (2018)	12
Data-centred carbon footprint analyses	Reduction of greenhouse gas emissions	Peukert et al. (2015)	13
Underwater wireless sensor networks	Ocean pollution prevention	Kao et al. (2017)	14
Smart forestry and big data	Predict changes to make quick decisions to reduce losses due to delays	Zou et al. (2019)	15
Smartphones	Mobile activism	Hanna (2017)	16
World statistics cloud	Monitoring the SDG agenda	Manoj (2017)	17

1.2 Rationale and purpose

These constraints make evident the challenges related to integrating IoT for sustainability. In addition, there are challenges related to integrating IoT into higher education generally, independent of those related to integrating IoT for sustainability. Aldowah et al. (2017) explained that there are additional technical issues that will need to be addressed. IoT depends on cloud computing which may present challenges related to latency in educational institutions. Security and privacy issues will require that higher education develop standards and strategies relevant to staff and students. Higher education will need to cover the costs of IoT integration such as those related to infrastructure and to training to prepare educators for new pedagogies. In general, these challenges suggest that the integration of IoT for sustainability may not be feasible in engineering education (EE).

There is a growing body of research on IoT in higher education (e.g., Silva et al., 2020) and in other areas such as entrepreneurship (e.g., Fernandes and Castela, 2019) and the service sector (Skaržauskienė and Kalinauskas, 2015). There have been studies of the implications for or the impact of IoT on EE in general (e.g., Vujovic and Maksimovic, 2015). There are a limited number of studies that consider how to integrate IoT in EE in ways that are sustainable (see Maksimović, 2017). However, the review of the literature conducted for this study did not uncover any research related to the feasibility or the potential ease of integrating IoT for sustainability in EE. Nor did the review identify any studies related to how best to educate engineers so that they can promote IoT for sustainability. Aldowah et al. (2017, p.7) argued that the integration of IoT in education will require a "dramatic shift in the traditional instructional paradigm." Problem-based learning (PBL) and project-based learning (PjBL) have been touted as relevant approaches for EE and sustainability (Guerra and Holgaard, 2013). However, there were no studies uncovered in the review for this study that identified pedagogies for EE that can foster IoT for sustainability.

The purpose of this study was, therefore, to identify the feasibility of and pedagogy related to integrating the IoT in EE in order to foster sustainability. This purpose is explored from the perspective of those most closely positioned to ensure that EE can promote IoT for sustainability, i.e., engineering educators. The specific research questions for this study were as follows:

1. What are engineering educators' perceptions of the feasibility of integrating IoT for sustainability in EE?
2. Are there differences in perceptions in relation to:
   a. the type of EE
   b. years of teaching experience
   c. level of teaching (e.g., bachelors or masters)
   d. knowledge of sustainability
   e. knowledge of IoT?
3. What additional factors do engineering educators identify in relation to the feasibility of integration of IoT for sustainability in EE?

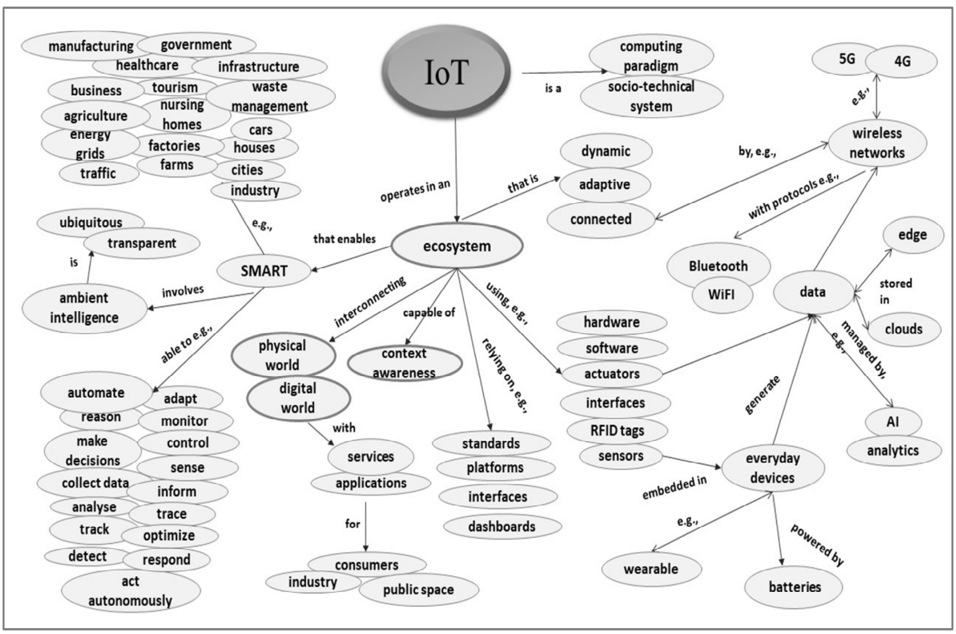
2 Background

2.1 Overview: the IoT

IoT is an umbrella term reflecting a technological evolution (RAE, 2018a) with a projected 75 billion connected devices in 2020 (Chin et al., 2019). While there is no agreed-upon definition (Chin et al., 2019), IoT has been referred to as an ecosystem (Mazhelis et al., 2012) that is adaptive and dynamic (Lee et al., 2016), a computing paradigm (Gomez et al., 2019), a network of networks (Miraz et al., 2015) or as a "comprehensive environment that interconnects a large number of heterogeneous physical objects or things to the internet" (Chang et al., 2019). For an overview of definitions of IoT and its phases of development in time, see Chin et al. (2019).

The IoT relies on a combination of emerging technologies (Chin et al., 2019) including but not limited to radio frequency identification devices (RFID tags), wireless sensor networks, WiFi, Bluetooth, ZigBee, sensors, actuators, embedded communication hardware, and tools for data analytics (Aldowah et al., 2017). IoT is partially driven by technological advances including those related to miniaturisation and semiconductors (Chin et al., 2019). Miniaturisation supports creation of wearable devices such as sensors for health monitoring (e.g., see Pantelopoulos and Bourbakis, 2010). Advances in wireless networks from 4th to 5th generation connectivity are also supporting growth of IoT (Wollschlaeger et al., 2017). IoT devices depend on battery technology because of their utility in mobile and distributed applications (Curry and Harris, 2019).

Figure 1 An overview of IoT



IoT is a key ingredient and enabler for the development of smart technologies (e.g., Google's Alexa) and for environments such as homes, factories, healthcare and cities (see Gomez et al., 2019). Smart environments are a form of ambient, ubiquitous and transparent intelligence that is capable of, for example, reasoning, adapting, controlling, sensing, responding, etc. (Cook et al., 2009). Ambient intelligence (AmI) relies on context awareness to create environments that can sense needs in an environment and collect data, reason about and act on the data to benefit and support users in the environment (Cook et al., 2009). Data are central to IoT and may be collected by sensors combined with actuators that can act on the data (RAE, 2018a). However, the amounts of data collected by such environments are vast and require big data analytics in order to extract value (Moreno et al., 2015). Cloud computing, data mining and artificial intelligence represent approaches to analysing large units of data (Cook and Das, 2012). Edge and fog computing may also be used to provide computational resources near the data sources to analyse data closer to where the IoT devices are located (Chang et al., 2019). Figure 1 provides an overview of IoT.

3 Implications for EE

Maximising the affordances and minimising the constraints of IoT for sustainability requires agency on the part of an actor. The agency, in this case, calls on the actor to identify and implement creative and innovative solutions to problems such as those targeted by the 17 SDGs. EE for sustainable development (EESD) is premised on the assumption that EE should play a socially-relevant role, for example, by 'tackling the challenges facing society' (Graham, 2018) and with engineers playing the role of change agents [Sheppard et al., (2006), p.431]. Guerra and Holgaard (2013) argued that, in order to contribute to sustainable societies, engineers as technological innovators, like the innovations themselves, must be shaped. Shaping engineers is the role of EESD. A focus on sustainability in education requires holistic and transformational, learner-centred teaching that is participative, self-directed, collaborative and problem-oriented (Rieckmann, 2018). Lehmann et al. (2008, p.283) posited that EE needs to move away from a discipline-oriented, lecture-centred, application of technical knowledge to a form that is more interdisciplinary, contextualised and student-centred. Resolution of sustainability-related problems demands key competencies as follows: systems', anticipatory, and normative thinking (Wiek et al., 2011).

Guerra and Holgaard (2013, p.1) identified PBL and PjBL with the corresponding principles of active and student-centred learning as a means to put EE 'on the right trajectory' to sustainability. PBL relies on a social constructivist approach in which students actively construct knowledge (Krogh-Hansen et al., 2014) in contextualised and meaningful learning contexts. PjPL is a form of experiential learning that mirrors professional practice and reflects the real world of work (Hanney, 2018). It draws on socio-cultural theories of learning (Lave and Wenger, 1991) according to which knowledge is not given but is dynamically constructed and emerges in practice in context and through interaction with others in a social setting (Lahiff et al., 2019).

PBL involves collaborative, student-directed formulation and resolution of real-life, ill-structured problems by applying interdisciplinary knowledge and strategies and engaging in skills such as critical and metacognitive thinking (Guerra, 2016). In PBL and PjBL, learning is centred around problems and executed through projects in which students must exercise social and communicative skills as they collaborate with peers (Lehmann et al., 2008). Projects are centred around problems chosen in conjunction with the project supervisor and that relate to course topics or themes (Lehmann et al., 2008). In PjBL, learners build understanding through interaction and integrating theory with practice (Lahiff et al., 2019). They do this autonomously, with choice, unsupervised and through exercising responsibility with instructors as facilitators who assess authentically (Thomas, 2000).

In addition to PBL and PjBL, future engineers will need specific IoT knowledge and skills. Their learning will need to include practice with and knowledge of information technologies such as networks, sensors, microprocessors, radio communication, network security and wireless sensing (Cai, 2019). This need places pressure on EE to provide for and integrate IoT technologies within courses and programs. However, the integration should be green (G-IoT) which requires that approaches emphasise energy-efficient, environmentally-friendly use, reduced resource consumption and avoidance of e-waste (Maksimović, 2017). Kiryakova et al. (2017) outlined some of the ways that IoT integration can benefit learners. Students can rely on their personal smart devices for interpersonal communication and interaction, to promote more active learning as well as access to real-time knowledge, information and experts. Smart devices can support personalisation through development of learners' profiles and data collection and analysis that allow for tracking progress and for creation of materials tailored to the learner, particularly those with special-educational needs (Kiryakova et al., 2017). The complexity of the IoT will require bridging between courses that are scientific and humanistic in order to give engineers the skills to communicate in multi-disciplinary teams (Corno et al., 2016).

4 Methods

4.1 Overview

Data collection relied on a self-report survey. The survey was available for online access by respondents through Survey Monkey (http://www.surveymonkey.com). The advantages of online data collection by this means include efficiency, convenience, savings of cost and time, global access, and easy transfer of data for analysis (Lefever et al., 2007).

4.2 Recruitment

To recruit participants, the researchers identified individuals involved in EE in Thailand by searching university, faculty and department websites. That initial search yielded 574 individuals. Of these, the researchers found the e-mail addresses for 498 individuals. Of those 498, 476 e-mails were accurate whereas 22 were returned with an undeliverable message. Of those 476, 113 individuals replied, after three reminders sent five to ten days apart.

4.3 Participants' demographics

Table 2 provides an overview of participants' demographics. The engineering educators represented a range of areas with the highest concentration being in electrical and industrial production engineering. There were no participants from certain areas of EE such as chemical engineering. There was a range of experience from five to 20 years. The majority were teaching at the bachelors' level. In terms of knowledge of sustainability, the majority reported only satisfactory knowledge. In terms of knowledge of IoT, only three participants reported a very high knowledge and only 26 reported high knowledge.

Table 2 Participant (N = 113) demographics

Demographics	*N*
Type of EE	
Electrical	20
Electronics	13
Computer	15
Telecommunication/electrical	14
Mechatronic/robotics	4
Mechanical	12
Civil	2
Industrial/production	19
Welding	1
Information and communication technology	3
Technical education	5
Other	5
Years of teaching experience	
< 5 years	17
5–10 years	24
11–15 years	20
16–20 years	14
> 20 years	38
Teaching level	
Vocational	1
Bachelors	94
Masters	8
Doctoral	10
Knowledge of sustainability	
Very high	3
High	25
Satisfactory	75
Low	10
Very low	0
Knowledge of the internet of things	
Very high	3
High	26
Satisfactory	75
Low	8
Very low	1

4.4 Instrument

The online survey consisted of an introductory section that outlined the study's purpose and research questions along with definitions of terms such as feasibility, IoT and sustainability. Contact information was provided for the principal investigator (PI) and participants were informed that they could contact the PI with any questions about the survey or their related participation. They were informed that the survey would take approximately 30 minutes to complete. The survey's introduction advised them that their participation was entirely voluntary and that survey responses were anonymous and confidential. They were also made aware that the survey did not require any information about their name or institution. The final part of the introduction advised them that clicking the 'submit' button at the end of the survey would constitute their consent to participate.

The next part of the survey was designed to collect demographic data (see Table 2) which could then be used for Research question 2. These data were aggregated so that no personal information could be collected or displayed. The next section of the survey included 40 items grouped into the following feasibility categories: overall feasibility for sustainability (see Figure 2); preparing students, engineering educators' approaches, engineering educators engaging students in learning, and thinking skills (see Tables 3–6). Cronbach's alpha for the 40 items was .961. Responses could be given using a four-point Likert-type scale of completely feasible (CF) (4), feasible for the most part (FfMP) (3), not very feasible (NVF) (2) and entirely unfeasible (EU) (1). The final section provided an opportunity for respondents to give an open-ended response about factors related to integration of IoT for sustainability in EE.

The instrument items were compiled based on the literature review conducted for this study, in particular, the implications for EE. For example, in that section, the researchers identified that maximising the affordances and minimising the constraints of IoT for sustainability requires agency. That agency is needed for individuals to be able to identify and implement creative and innovative solutions to problems such as those targeted by the 17 SDGs. The corresponding instrument item is presented in Table 3: the feasibility of preparing students to play the role of agents of change. The instrument's focus on thinking skills (see Table 6) was also previously identified in the literature review. Items in Table 6 were in recognition of Wiek et al.'s (2011) argument that resolution of sustainability-related problems demands key competencies as follows: systems' anticipatory and normative thinking.

4.5 Data analysis

Survey items were calculated and reported using percentages for Research question 1. For Research question 2, two-way ANOVA was used to identify any significant differences related to demographic variables and feasibility. For Research question 3, the open-ended responses were first translated by the PI into English. Next, data reduction was conducted to sharpen, sort, focus, discard data [Miles and Huberman, (1994), p.11] and to eliminate data not relevant or comprehensible. Next, the data were read and reread to "to obtain the sense of the whole" [Bengtsson, (2016), p.11]. The next step involved inductive identification of keywords and patterns (Miles et al., 2014). That stage of analysis led to the identification of categories.

5 Results

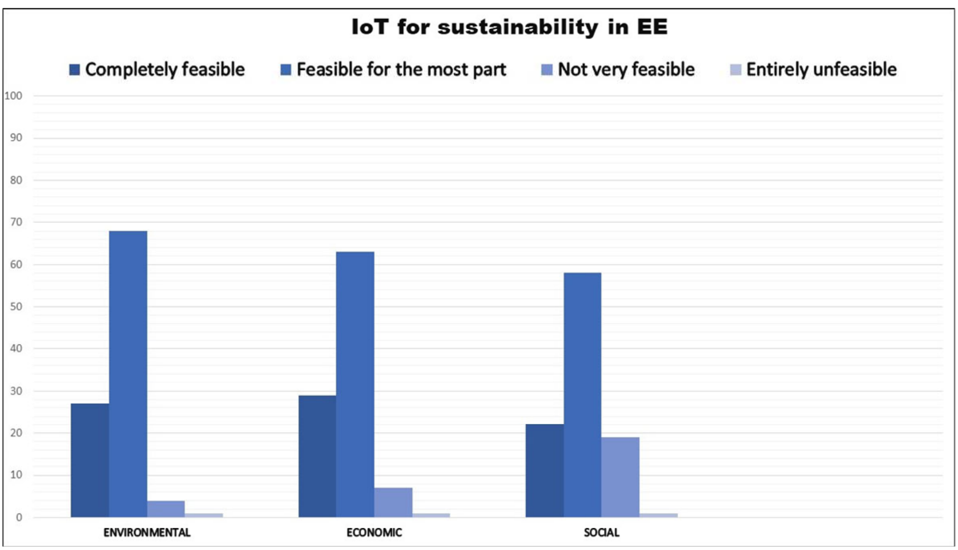
5.1 Results for Research question 1

Research question 1 asked: what are engineering educators' perceptions of the feasibility of integrating IoT for sustainability in EE?

5.1.1 Results for sustainability

Figure 2 presents the overall results for the feasibility of integrating IOT for sustainability in EE. Regarding the three pillars of sustainability, 27% of respondents reported that integrating IoT for environmental sustainability was 'CF' and 68% reported that it was 'FfMP'. For economic sustainability, results were similar with 29% for CF and 63% for FfMP. Results for social sustainability were somewhat lower with 22% reporting CF and 58% for FfMP Normally, a sentence should not begin with a numeral which is why we wrote in the original 20%.

Figure 2 Overall feasibility for sustainability (see online version for colours)



5.1.2 Feasibility of preparing students

Table 3 presents results related to the feasibility of preparing students for various learning roles and behaviours in relation to IoT for sustainability. Feasibility items are indicated as follows: CF, FfMP, NVF and EU. Items are ranked high to low with totals for categories of CF + FfMP and NVF + EU posted under each item in italic. Table 3 shows that the majority of respondents perceived that it was feasible to prepare students for the integration of IoT for sustainability. The least feasible item was 'focus on problems that reflect the complexity of the real world of work' (87%).

Table 3 Feasibility of preparing students

<table>
<tr><th>Prepare students to</th><th>CF %</th><th>FfMP %</th><th>NVF %</th><th>EU %</th></tr>
<tr><td rowspan="2">Be technological innovators</td><td>45</td><td>52</td><td>3</td><td>0</td></tr>
<tr><td colspan="2">97</td><td colspan="2">3</td></tr>
<tr><td rowspan="2">Implement creative and innovative solutions to problems</td><td>45</td><td>51</td><td>4</td><td>0</td></tr>
<tr><td colspan="2">96</td><td colspan="2">4</td></tr>
<tr><td rowspan="2">Use their personal smart devices for interpersonal communication</td><td>44</td><td>51</td><td>4</td><td>1</td></tr>
<tr><td colspan="2">95</td><td colspan="2">5</td></tr>
<tr><td rowspan="2">Use smart devices to personalise learning</td><td>38</td><td>55</td><td>4</td><td>3</td></tr>
<tr><td colspan="2">93</td><td colspan="2">7</td></tr>
<tr><td rowspan="2">Communicate in multi-disciplinary teams</td><td>47</td><td>46</td><td>6</td><td>1</td></tr>
<tr><td colspan="2">93</td><td colspan="2">7</td></tr>
<tr><td rowspan="2">Access real-time knowledge, information and experts</td><td>45</td><td>47</td><td>6</td><td>2</td></tr>
<tr><td colspan="2">92</td><td colspan="2">8</td></tr>
<tr><td rowspan="2">Actively construct knowledge</td><td>34</td><td>56</td><td>10</td><td>0</td></tr>
<tr><td colspan="2">90</td><td colspan="2">10</td></tr>
<tr><td rowspan="2">Integrate theory with practice</td><td>45</td><td>45</td><td>8</td><td>2</td></tr>
<tr><td colspan="2">90</td><td colspan="2">10</td></tr>
<tr><td rowspan="2">Play the role of agents of change</td><td>32</td><td>57</td><td>11</td><td>0</td></tr>
<tr><td colspan="2">89</td><td colspan="2">11</td></tr>
<tr><td rowspan="2">Focus on problems that reflect the complexity of the real world of work</td><td>33</td><td>54</td><td>12</td><td>1</td></tr>
<tr><td colspan="2">87</td><td colspan="2">13</td></tr>
</table>

5.1.3 Feasibility of engineering educators' approaches

Table 4 presents results of the survey that pertained specifically to approaches that engineering educators can take to integrate IoT for sustainability. The majority of respondents indicated that educators could integrate IoT for sustainability, however, the feasibility was relatively less for two items in particular: 'develop students' interpersonal competencies' (84%) and 'develop students' social skills' (76%). These are items that, although related to sustainability, may be unfamiliar approaches in EE.

5.1.4 Feasibility of engineering educators engaging students in learning

Table 5 presents results of engineering educators' perspectives on the feasibility of engaging students in the forms of learning that were identified in the study's literature review as being relevant for integrating IoT for sustainability. The majority of respondents (> 90%) identified engagement in these forms of learning as CF or FfMP. However, interactive (83%) and social learning (81%) were the lowest ranked in terms of feasibility. These are forms of learning that may be less common in EE and potentially in the sciences.

Table 4 Feasibility of engineering educators' approaches

Engineering educators can	*CF %*	*FfMP %*	*NVF %*	*EU %*
Act as facilitators	52	46	2	0
	98		*2*	
Integrate IOT technologies within courses and programs	47	48	4	1
	95		*5*	
Use technology to develop learner profiles	41	54	4	1
	95		*5*	
Use technology to create content tailored to the learner	44	50	6	0
	94		*6*	
Track students' progress using data collection and analysis	37	57	6	0
	94		*6*	
Rely on authentic assessment	33	61	6	0
	94		*6*	
Integrate courses that are scientific and humanistic	35	58	7	0
	93		*7*	
Provide opportunities for decision making	37	55	8	0
	92		*8*	
Promote 'green' use of technology	33	57	9	1
	90		*10*	
Develop students' interpersonal competencies	29	55	15	1
	84		*16*	
Develop students' social skills	22	54	23	1
	76		*24*	

5.1.5 Feasibility of engaging in thinking skills

Table 6 presents results of engineering educators' perspectives on the feasibility of engaging students in thinking skills that were identified in the study's literature review as being relevant for integrating IoT for sustainability. A high percentage of respondents identified engagement in these forms of thinking as CF or FfMP. Normative thinking (related to norms of justice, equity and integrity) was the lowest ranked (79%) for CF or FfMP. This may be because, unlike the more commonly referred to forms of thinking such as holistic, critical and metacognitive, respondents may be less familiar with normative thinking.

5.2 Results for Research question 2

Research question 2 asked: are there differences in perceptions of integrating IoT for sustainability in EE in relation to:

a the type of EE

b years of teaching experience

c level of teaching (e.g., bachelors or masters)

d knowledge of sustainability

e knowledge of IoT.

Table 7 presents the results of ANOVA to identify any significant differences for perceptions of integrating IoT for sustainability in EE in relation to the demographic variables. No significant differences were identified for any of the demographic variables. This result is in spite of the wide range in these variables. For example, in terms of the areas which the respondents reported working in, these ranged from more than 11 different areas. Similarly, there was a wide range in the years of teaching experience from fewer than five years to more than 20. The majority indicated satisfactory knowledge of both sustainability and IoT. This result suggests uniformity in the perceptions.

Table 5 Feasibility of engineering educators engaging students in learning

Engineering educators can engage students in learning that is	*CF %*	*FfMP %*	*NVF %*	*EU %*
Collaborative	52	44	4	0
	96		*4*	
Learner-centred	47	48	5	0
	95		*5*	
Problem-oriented	49	46	5	0
	95		*5*	
Self-directed	42	53	4	1
	95		*5*	
Project-based	46	48	5	1
	94		*6*	
Meaningful	32	62	6	0
	94		*6*	
Holistic	39	54	5	2
	93		*7*	
Interdisciplinary	38	54	8	0
	92		*8*	
Contextualised	27	63	10	0
	90		*10*	
Interactive	33	50	16	1
	83		*17*	
Social	20	61	19	0
	81		*19*	

Table 6 Feasibility of engaging in thinking skills

Engineering educators can engage students in thinking that is	*CF %*		*FfMP %*	*NVF %*		*EU %*
Holistic, interconnected, (systems')	35		58	6		1
		93			*7*	
Metacognitive	31		57	10		2
		88			*12*	
Anticipatory (to foresee harmful consequences)	28		58	13		1
		86			*14*	
Critical	30		55	14		1
		85			*15*	
Normative (related to norms of justice, equity and integrity)	17		62	20		1
		79			*21*	

5.3 Results for Research question 3

The survey asked respondents to identify any additional issues related to the feasibility of integration of IoT for sustainability in EE. Analysis led to the grouping of responses into the following categories: curricula and program factors, instructor and student-related factors, administrative and policy factors, and technology-related factors. The factors for each of these categories are outlined in the following sections.

5.3.1 Curricula and program factors

The factors related to curricula and programs include the need to promote critical thinking, online learning, learning about hardware and programming and about modern technology. Student participation should be encouraged, and all learners should have equal opportunity to access various technologies as well as access to more individualised learning to take into account student differences. Learners should use the internet for learning more than for playing games. They should be encouraged to see the necessity of learning about IoT and its real-life applications. There should be promotion of knowledge about real work for use in PjBL and networking, for example, with industrial factories. Professional training should also take place in real workplace settings. Programs should involve integration of project and PBL. PBL must emphasise sustainability. There should be specific courses focused on IoT and videos should be created to introduce various IOT applications. Integration of IoT will require modifying fixed standards and inflexible learning frameworks. It will also require reducing the large number of courses and identifying unnecessary courses. IoT learning should be integrated with other disciplines and there should be a learning management model suitable for IoT implementation. Feedback from stakeholder groups can be used to guide curriculum development related to IoT. In addition to learning, there should be opportunities to conduct research on IoT.

Table 7 Results of ANOVA

	N	$\bar{x}$	*SD*	*F*	*Sig.*
Type of EE					
Electrical	20	3.29	.425	1.201	.296
Electronics	13	3.28	.260		
Computer	15	3.42	.339		
Telecommunication/electrical	14	3.28	.300		
Mechatronic/robotics	4	3.40	.407		
Mechanical	12	3.13	.388		
Civil	2	3.24	.088		
Industrial/production	19	3.02	.407		
Welding	1	3.28	-		
ICTs	3	3.48	.472		
Technical education	5	3.42	.465		
Other	5	3.28	.425		
Years of experience					
< 5	17	3.24	.361	.691	.600
5–10	24	3.21	.453		
11–15	20	3.18	.465		
16–20	14	3.40	.368		
> 20	38	3.27	.359		
Teaching level					
Vocational	1	3.18	-	2.282	.083
Bachelors	94	3.28	.388		
Masters	8	2.91	.529		
Doctoral	10	3.34	.310		
Level of knowledge of sustainability					
Very high	3	3.31	.253	1.936	.128
High	25	3.11	.472		
Satisfactory	75	3.28	.344		
Low	10	3.44	.550		
Very low	0				
Level of IoT knowledge					
Very high	3	3.37	.188	1.478	.214
High	26	3.15	.473		
Satisfactory	75	3.27	.369		
Low	8	3.34	.417		
Very low	1	4.00	-		
Totals for all categories	113	3.26	.400		

5.3.2 Instructor and student-related factors

Both instructors and students must have awareness and understanding of, experience with and the right attitude for IoT. Their knowledge must be able to keep pace with new technology. Students will need to be able to realise the importance of IoT. They should be self-motivated about it and have an interest in it. They also need to be able to think critically about it. Students and instructors must make use of technology to the maximum benefit. Students will need readiness to use hardware and software and require skills in IoT, artificial intelligence and big data. Instructors will need time to prepare for the design of learning for IoT. They will also need to understand the significance of IoT. Instructors who are still adhering to traditional learning management styles need to adapt. Overall, instructors will need expertise in IoT.

5.3.3 Administrative and policy factors

Thailand needs to deal with obstacles and lack of experience in working as a team culture. There must be executive, government and corporate support and cooperation at all levels. This means that organisations must share resources and participation and there should be a vision from the organisations' leaders. There must be an efficient management system and public relations to create awareness so that relevant parties can see the benefits of IoT. IoT needs media attention. There also needs to be awareness of the importance and necessity of technology in daily life. Policies should help increase opportunities for IoT integration in education. Low-income students will need financial supports. Regulations and laws must support IoT integration. Clear procedures will support integration and promotion of IoT. Infrastructure will be needed to introduce IoT. Support will be needed for readiness in various fields from relevant departments. Instructors must be supported by the relevant sections. Economic factors should be taken into account to reduce costs and make the most of resources. Budgets and capital should support the provision of training materials and software and access to new technology. There need to be fundamental investments in technology and internet networks. At the same time, costs should be reduced and efficiency increased.

5.3.4 Technology-related factors

Technology-related factors include promoting broader access to internet and equipment to ensure equality of opportunities in terms of access. Some communities are still without internet access, yet the internet must be available in all areas. Network equipment must be available, and all locations supported. Lack of availability of modern equipment can slow adoption. IoT-related systems must be robust, stable and strong or they may crash. High-speed Internet and various devices must be sufficient for IoT. Sufficient speeds are necessary for uploading and downloading large amounts of data. Domestic communication systems must be ready for IoT. Ecosystems need to be created that connect to every platform. The technology is constantly changing, therefore, its design should take into account that, although technology may be created to solve problems, there will always be a need for new technologies to solve other problems that arise. In the case of IoT, data security is important because dangers can arise that violate privacy. Network security must be a priority. Reliance on the university's internet system that requires a login via a webpage must be designed in a way that makes it convenient to use IoT.

6 Discussion

The purpose of this study was to identify the feasibility of and pedagogy related to integrating the IoT in EE in order to promote environmental, social and economic sustainability. This purpose was explored from the perspective of those mostly closely positioned to ensure that EE can promote IoT for sustainability, i.e., engineering educators. The study first asked what are engineering educators' perceptions of the feasibility of integrating IoT for sustainability in EE? For most of the items, in excess of 90% reported that the items listed in the survey were either CF or FfMP. Results point to the potential feasibility of pedagogical approaches that rely on student-centred PjBL and PBL.

However, there appeared to be a potential pattern in terms of items that 10% or more of respondents indicated as NVF or EU. Those items related more to social aspects of integrating IoT. 20% of respondents indicated that promoting social sustainability in EE was 'NVF' and 'EU' compared to only 5% for environmental and 8% for economic. Similarly, the lowest ranked items related to the feasibility of engineering educators' approaches were: 'develop students' interpersonal competencies' (84%) and 'develop students' social skills' (76%). The lowest-ranked items for the types of approaches in which educators could engage learners were interactive (83%) and social (81%). In terms of thinking skills, it is those related to society (i.e., normative) that were ranked lowest (79%) in the category. The fact that social sustainability and these socially-related items are ranked low should not be surprising. In spite of the link between economic efficiency and social progress (Zarei et al., 2016), the social dimension "garners less attention and is particularly difficult to realize and operationalize" (Boström, 2012).

Research question 2 focused on identifying any significant differences between the demographic variables and perceptions of feasibility. No significant differences were identified. This result suggests that perceptions of feasibility are generally uniform for these respondents and are not influenced by variables such as years of experience, or even by knowledge of IoT or of sustainability. This is a hypothesis that could be tested in other studies. Regarding this knowledge, it is of interest and relevance to note that 75 of 113 respondents rated their knowledge as merely satisfactory. While there have been studies of students' knowledge of sustainability (e.g., Thürer et al., 2017), there has been less attention to the knowledge of engineering educators. Similarly, attention to measures of engineering educators' knowledge of IoT has been neglected in the literature. These are areas that could be explored in future studies.

Regarding Research question 3, engineering educators identified factors related to the feasibility of integration of IoT for sustainability in EE. The researchers organised these into categories related to curricula, people (teachers and students), administration and policy and technology. Across these categories, the issue of readiness and the need to prepare for integration of IoT was forefront. Readiness relates to having appropriate supports in place. These supports include technical, financial, infrastructure or professional development issues to name but some. It is interesting to note that respondents' perspectives of the related factors highlighted not only technical challenges and requirements but social, personal and economic challenges. Regardless of how receptive students and instructors are to educational integration of IoT for sustainability, there must be attention to these factors. This attention will require technical infrastructure, new policies and standards, and changes to pedagogical approaches.

Tianbo (2012) identified similar changes that will be required in education, in terms of changes in teaching, learning and management. In relation to feasibility or ease of integration, the challenges may be formidable. Future research may focus on pedagogical issues for the integration of IoT for sustainability in EE. However, the feasibility will depend not only on pedagogy but on other related, complex factors similar to those identified by respondents in this study.

In relation to the survey, those interested in using it in their context for investigating IoT for sustainability in EE can also add other factors such as those identified in relation to Research question 3. In addition, the survey could be used in areas other than EE such as computer science or with a specific group within EE such as those directly involved in IoT hardware and software development and in data storage and analysis. From the perspective of policy, this study suggests that engineering educators perceive that it is feasible to integrate IoT for sustainability in EE. More specifically, the study has highlighted the feasibility of approaches such as PBL and PjBL. Universities and other institutions responsible for the delivery of EE can provide the supports (budget, readiness training, technology infrastructure, etc.) in order to make integration of IoT for sustainability not only feasible but actual reality. Policies should help increase opportunities for IoT integration in education. The study has also highlighted that a focus on IoT itself is insufficient. Instead, there needs to be recognition of the importance of agency in relation to adoption and implementation of the new technologies. Such agency is particularly relevant for those at the forefront who are designing and delivering the learning that can maximise the affordances of IoT for sustainability and minimise the constraints. These individuals have a role to play in deploying the technologies that, ultimately, can contribute to a more sustainable world.

7 Conclusions

This study adds to the literature by connecting three different phenomena: EE, sustainability and IoT. Although there is a growing body of research on IoT and sustainability, this study represents one of the first contributions to the feasibility of integrating IoT for sustainability in EE. This study's results should be considered in relation to its limitations. The response rate for the survey was 24%. Given this rate, findings may be affected by selection bias (see Heckman, 2010) which, in turn, may affect the external validity of results. Bethlehem (2010) explained that online surveys can result in non-response for various reasons including but not limited to internet access and technical problems. The broad range of responses does, however, provide some evidence of what may be true for the larger population. The demographic characteristics reported by participants revealed a range of types of EE, knowledge of sustainability and of IoT, experience and levels taught. The exception is that there were few respondents from the vocational level. Future studies could specifically target this group. The survey itself was designed specifically for this study as the researchers' review of the literature did not uncover any other instruments pertaining to the feasibility of IoT for sustainability in EE.

An additional limitation is that the study was conducted in only one country which may not be representative of contexts of IoT in other countries particularly those that are not in Asia. However, Thailand can be considered a highly relevant context in which to investigate the phenomenon. Thailand's Telecommunication Master Plan conforms to the ASEAN ICT Masterplan 2020. The latter focuses on promoting the IoT as a means to develop an advanced digitally-enabled economy (ASEAN, 2015). The country's economic model, Thailand 4.0 (see https://thaiembdc.org/thailand-4-0-2/) depends on IoT, big data and advanced technologies in order to improve production and promote innovation. At the same time, the country has made an explicit commitment to the 2030 Agenda for Sustainable Development (Government of Thailand, 2018).

The review of the literature conducted for this study did not identify any country-specific studies related to integrating IoT for sustainability in EE. However, public policy documents (Public Policy Forum, 2016) related, for example, to Canada, suggests that a major challenge will involve finding the required talent to implement IoT. In addition, as with many countries, there will be a need to address issues of security and privacy. Furthermore, unlike Thailand, IoT integration in Canada may occur more slowly because of a lack of "advanced connectivity infrastructure necessary for the coming wave of connected devices" (Public Policy Forum, 2016). Given that both IoT and sustainability are global phenomena, countries will likely benefit from cooperation and collaboration in efforts to increase the feasibility of integrating IoT for sustainability in EE specifically and in higher education in general.

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