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SURVEY ARTICLE

Internet-of-Gamification: A Review of Literature on IoT-enabled Gamification for User Engagement

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ABSTRACT

Engagement is a common goal pursued by most social and technical systems, because of its widely acknowledged effects on enhancing user acceptance and performance. Previous research has shown that a system's ability to engage users involves two known aspects: the technology foundation that determines the interactive paths for engaging users and the design methodology that determines the atop user experience to be conveyed through those paths. In recent years, an emerging and promising engagement approach that integrates both an advanced technology stack and novel design methodology, i.e. IoT-enabled Gamification (IeG), has attracted wide interest from both public and private sectors. This article aims to conduct a systematic review to answer some fundamental questions. 75 papers were reviewed under a 3-axis analysis framework of user engagement, the majority of which indicated that IeG is linked to increased engagement in a variety of application domains, stages, and population scales.

1. Introduction

In the last decade, the Internet of Things (IoT) has been well developed from its embryo of industrial application and is now considered as a key impetus for the digitization of our society and economy.[1] To this end, the active involvement of people and collective wisdom generated by co-creation and co-innovation have been unprecedentedly emphasized in this progress. Horizon Europe, the largest science and research project in Europe, listed public engagement as one of its core targets.[2] According to a Gallup report, employee engagement and customer engagement were considered as the key factors for business success and innovation.[3] Furthermore, SmartCitiesWorld has claimed that smart cities would not thrive without the active engagement of citizens.[4] User engagement hence becomes one of the common design and development goals shared by many recent IoT-based systems and smart services, where people play a profound, multi-faceted role combining data consumer, data contributor, and a provider of intelligence and other potential value Table 1–5.

Meanwhile, gamification is a design approach of enhancing services and systems with affordances for experiences similar to those created by games (Koivisto & Hamari, 2019). By transforming systems and services to afford a gameful experience (Hamari, 2007), gamification presents itself as a de facto approach for increasing user engagement in various application domains such as health, education, governance, marketing, and others (Hanus & Fox, 2015; Hassan & Hamari, 2020; Hofacker et al., 2016). In recent years, a rising trend of integrating smart technologies and gamification has been witnessed in both public and private sectors for the purpose of better user engagement. The term "smart gamification" was coined to describe the technical convergence in a broader sense that also covered a wider range of smart technologies like machine learning, intelligent agent, and such (Uskov & Sekar, 2015). However, in this article, we intend to investigate a more concentrated research scope, namely, "**IoT-enabled gamification (IeG)**." We argue that this approach is increasingly being combined with smart society and industry development agendas, eventually forming an Internet-like information infrastructure that consists of enormous smart gamification systems/services across a vast range of application domains, e.g., the playful city, somatosensory health/education games, and gamification in industry 4.0..

However, even though a certain number of IoT-enabled gamification applications are present, there is still a scant systematic and comprehensive overview, thus hindering a consistent body of knowledge in this area. Although user engagement can actually manifest itself in various forms and scales, the existing literature barely takes this situation into account. Rather, the topic is investigated in a broad and rough way, without conclusions of designable system factors nor a comprehensive evaluation of efficacy. As a consequence, the value of IoT-enabled gamification systems has not been fully synthesized and conveyed, and pragmatic design guidelines for potential practitioners have not been established.

Therefore, this paper aims to propose a systematic conceptual framework to conclude the existing literature body of IoT-enabled gamification and its applications on user engagement by way of a comprehensive and in-depth literature review, extract reusable methods and knowledge, and further contribute to both theoretical and pragmatic foundations for future research in this area.

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Table 1. Bibliometric data.

Discipline	Amount	Year	Amount	Publication Type	Amountt
Sociology	16	2020	1	Conference Paper	51
Psychology	6	2019	17	Article	21
Computer Science	50	2018	15	Book Chapter	3
Information Science	44	2017	18		75
Engineering	8	2016	9		
Management	2	2015	8		
Art and Design	7	2014	3		
		2012	2		
		2011	1		
		2008	1		
			75		

Table 2. Typological metrics.

Type	Amountt	Reference
Empirical	36	(Agyeman & Al-Mahmood, 2019; Alexandre et al., 2019; Ardito et al., 2018; Bahadoor & Hosein, 2016; Briones et al., 2018; Casals et al., 2017; Chen et al., 2017; Dange et al., 2016; Dessureault, 2019; García et al., 2017; Henry et al., 2018; Hwang et al., 2012; Karime et al., 2012; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019; Konstantinidis et al., 2014; L'Heureux et al., 2017; Lapão et al., 2016; Lu, 2018; Miglino et al., 2014; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Pokric et al., 2015; Poslad et al., 2015; Postolache et al., 2019; Pozzi & Sgardelis, 2016; Radeta et al., 2019; Rock Zou et al., 2015; Tan & Varghese, 2016; Wilkowska et al., 2015; Williams et al., 2019; Winnicka et al., 2019)
Research-in-Progress	29	(Ahuja & Khosla, 2019; Amaro & Oliveira, 2019; Büsching et al., 2016; Butgereit & Martinus, 2016; Cherner et al., 2019; Diego et al., 2018; Ding et al., 2014; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; Gabrielli et al., 2014; Garcia-Garcia et al., 2017; Gawley et al., 2016; Innocent, 2016; Kobeissi et al., 2017; Koutsouris et al., 2018; Krommyda et al., 2018; Laine & Sedano, 2015; Madar et al., 2014; Mann et al., 2019; Massoud et al., 2019; Monge & Postolache, 2018; Õunapuu, 2015; Quintas et al., 2016; Song et al., 2016; Spyrou et al., 2018; Tziortzioti et al., 2018; Wang & Hu, 2017)
Conceptual	10	(Ben-Moussa et al., 2017; Caivano et al., 2017; Fahlquist et al., 2011; Hong & Cho, 2018; Pargman et al., 2017; Penders et al., 2018; Pouryazdan et al., 2017; Rowland, 2015; Spyrou et al., 2018; Van Der Helm, 2008)
Total	75	

Table 3. Application domains.

Application Domain	Amountt	Reference
Sustainability	21	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Briones et al., 2018; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Dessureault, 2019; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019; Krommyda et al., 2018; Lapão et al., 2016; Lu, 2018; Miglino et al., 2014; Mylonas et al., 2019; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Penders et al., 2018; Pokric et al., 2015; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Rock Zou et al., 2015; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Winnicka et al., 2019)
Health Care/Well being	22	(Agyeman & Al-Mahmood, 2019; Alexandre et al., 2019; Ben-Moussa et al., 2017; Büsching et al., 2016; Butgereit & Martinus, 2016; Gabrielli et al., 2014; Gawley et al., 2016; Hong & Cho, 2018; Hwang et al., 2012; Karime et al., 2012; Konstantinidis et al., 2014; Laine & Sedano, 2015; Madar et al., 2014; Mann et al., 2019; Monge & Postolache, 2018; Oliver et al., 2018; Pargman et al., 2017; Postolache et al., 2019; Song et al., 2016; Tan & Varghese, 2016; Van Der Helm, 2008; Wilkowska et al., 2015)
Education	15	(Cherner et al., 2019; Henry et al., 2018; Kihara et al., 2019; Kobeissi et al., 2017; Laine & Sedano, 2015; Miglino et al., 2014; Mylonas et al., 2019; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Pokric et al., 2015; Rock Zou et al., 2015; Spyrou et al., 2018; Tziortzioti et al., 2018; Wang & Hu, 2017)
Crowd Sourcing	7	(Chen et al., 2017; Kimura & Nakajima, 2019; Krommyda et al., 2018; L'Heureux et al., 2017; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016; Tziortzioti et al., 2018)
Skill Training	6	(Bahadoor & Hosein, 2016; Dange et al., 2016; Lapão et al., 2016; Mann et al., 2019; Quintas et al., 2016; Williams et al., 2019)
Smart Home/Home Automation	6	(Caivano et al., 2017; Cherner et al., 2019; Lu, 2018; Õunapuu, 2015; Penders et al., 2018; Winnicka et al., 2019)
Tourism	4	(Amaro & Oliveira, 2019; Ardito et al., 2018; Fahlquist et al., 2011; Fischöder et al., 2018)
Smart Building	3	(L'Heureux et al., 2017; Rowland, 2015; Spyrou et al., 2018)
Transportation	3	(Fernandes et al., 2020; Kazhamiakin et al., 2016; Poslad et al., 2015)
Industry	2	(Dessureault, 2019; Oliveri et al., 2019)
Entertainment	2	(Innocent, 2016; Radeta et al., 2019)
General Purpose	2	(Koutsouris et al., 2018; Radeta et al., 2019)
Energy	1	(Ding et al., 2014)

2. Concepts and analysis framework

2.1. Internet of things

The Internet of Things, or IoT, was first introduced by Kevin Ashton to describe how a new kind of pervasive technology can be created by "adding radio-frequency identification and other sensors to everyday objects" (Ashton, 2009). It is a technical paradigm following Mark Weiser's vision that: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser, 2002). Over time, the term has been specified and redefined in several ways. Some define it as "an open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment" (Madakam et al., 2015), while others refer to it as "a system of uniquely identifiable objects (things) and virtual addressability that would create an Internet-like structure for remote locating, sensing, operating, and/or actuating of entities" (Ng & Wakenshaw, 2017). Nevertheless, most believe IoT will pave the road toward an Internet of People (IoP) (Conti et al., 2017) and an Internet of Everything (IoE) (Miraz et al., 2015), further leading to a world where all humans, physical objects, and digital services can be connected and communicate in an intelligent fashion.

Table 4. Cognitive-behavioral outcome.

Seperated Cognitive Outcome	Amount	Reference
Attention	40	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Briones et al., 2018; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Dessureault, 2019; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019; Krommyda et al., 2018; Lapão et al., 2016; Lu, 2018; Miglino et al., 2014; Mylonas et al., 2019; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Penders et al., 2018; Pokric et al., 2015; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Rock Zou et al., 2015; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Winnicka et al., 2019)
Attitude	44	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Briones et al., 2018; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Dessureault, 2019; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019; Krommyda et al., 2018; Laine & Sedano, 2015; Lapão et al., 2016; Lu, 2018; Madar et al., 2014; Miglino et al., 2014; Mylonas et al., 2019; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Penders et al., 2018; Pokric et al., 2015; Postolache et al., 2019; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Rock Zou et al., 2015; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Williams et al., 2019; Winnicka et al., 2019)
Motivation	72	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Alexandre et al., 2019; Amaro & Oliveira, 2019; Ardito et al., 2018; Bahadoor & Hosein, 2016; Ben-Moussa et al., 2017; Briones et al., 2018; Büsching et al., 2016; Butgereit & Martinus, 2016; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Cherner et al., 2019; Dange et al., 2016; Dessureault, 2019; Diego et al., 2018; Ding et al., 2014; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; Gabrielli et al., 2014; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Karime et al., 2012; Kazhamiakin et al., 2016; Kimura & Nakajima, 2019; Kobeissi et al., 2017; Konstantinidis et al., 2014; Koutsouris et al., 2018; Krommyda et al., 2018; L'Heureux et al., 2017; Laine & Sedano, 2015; Lapão et al., 2016; Lu, 2018; Madar et al., 2014; Mann et al., 2019; Massoud et al., 2019; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Pargman et al., 2017; Penders et al., 2018; Poslad et al., 2015; Postolache et al., 2019; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Radeta et al., 2019; Rock Zou et al., 2015; Rowland, 2015; Song et al., 2016; Spyrou et al., 2018; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Van Der Helm, 2008; Wilkowska et al., 2015; Williams et al., 2019; Winnicka et al., 2019)
Behavior	72	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Alexandre et al., 2019; Amaro & Oliveira, 2019; Ardito et al., 2018; Bahadoor & Hosein, 2016; Ben-Moussa et al., 2017; Briones et al., 2018; Büsching et al., 2016; Butgereit & Martinus, 2016; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Cherner et al., 2019; Dange et al., 2016; Dessureault, 2019; Diego et al., 2018; Ding et al., 2014; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; Gabrielli et al., 2014; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Kazhamiakin et al., 2016; Karime et al., 2012; Kimura & Nakajima, 2019; Kobeissi et al., 2017; Konstantinidis et al., 2014; Koutsouris et al., 2018; Krommyda et al., 2018; L'Heureux et al., 2017; Laine & Sedano, 2015; Lapão et al., 2016; Lu, 2018; Madar et al., 2014; Mann et al., 2019; Massoud et al., 2019; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Pargman et al., 2017; Penders et al., 2018; Poslad et al., 2015; Postolache et al., 2019; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Radeta et al., 2019; Rock Zou et al., 2015; Rowland, 2015; Song et al., 2016; Spyrou et al., 2018; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Van Der Helm, 2008; Wilkowska et al., 2015; Williams et al., 2019; Winnicka et al., 2019)

IoT is becoming a fundamental construction of modern information infrastructure, the application of which can be widely found in a large amount of commercial and open public services. With the prevalence of low-cost, low-power consumption transducers and transducer-embedded smart devices, we have witnessed the emergence of large-scale Wireless Sensor Networks (WSN) for environment monitoring, all the way to the Personal/Body Area Networks (PAN/BAN) that quantify an individual's daily life and biometric information. An unprecedented level of data awareness and data accessibility has greatly influenced not only how we perceive the surrounding world but also our decision making and behavior patterns (Conti et al., 2017). The data conglomerate can increase the overall interactability of smart services by providing highly personalized feedback and contextual awareness in a fine-grained granularity. Compared with contemporary legacy systems, the introduction of IoT was proved able to improve energy efficiency (Moreno et al., 2014), reduce time and resource consumption (Malavade & Akulwar, 2016; TongKe, 2013), hence lowering the overall interaction cost. Furthermore, these rapidly developing automation systems also enhance users' capabilities and their control over the services. Thus, IoT constitutes a technical affordance for engaging users in smart services.

2.2. Gamification

Gamification refers to a design approach of enhancing services and systems with affordances for experiences similar to those created by games (Koivisto & Hamari, 2019). It is considered an effective strategy to engage users in desired behaviors by restructuring tasks and activities to integrate game elements and provide gameful experiences. Research in the fields of health (Cugelman, 2013), education (Al-Azawi et al., 2016), tourism (Xu et al., 2017), business (Hofacker et al., 2016), and many others has shown that gamification can promote healthy behaviors, improve learning performance/motivation, or contribute to brand awareness/loyalty. However, the underlying mechanism of gamification still needs further research. Some have argued that gamification provides an engaging user experience because it can:

(1) Transport users into a virtual world or alternate reality by immersive and interactive narratives where a desired attitude or behavior can be gained more easily (Burrows & Blanton, 2016). A broader projection mechanism can be found in gamified applications, e.g., storification,

Table 5. Engagement stage.

Engagement Stage	Amount	Reference
Entry Point of Engagement	39	(Ahuja & Khosla, 2019; Briones et al., 2018; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Dessureault, 2019; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019; Krommyda et al., 2018; Lapão et al., 2016; Lu, 2018; Miglino et al., 2014; Mylonas et al., 2019; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Penders et al., 2018; Pokric et al., 2015; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Rock Zou et al., 2015; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Winnicka et al., 2019)
Sustained Engagement	69	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Alexandre et al., 2019; Amaro & Oliveira, 2019; Ardito et al., 2018; Bahadoor & Hosein, 2016; Ben-Moussa et al., 2017; Büsching et al., 2016; Butgereit & Martinus, 2016; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Cherner et al., 2019; Dange et al., 2016; Dessureault, 2019; Diego et al., 2018; Ding et al., 2014; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fraternali et al., 2017; Gabrielli et al., 2014; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Karime et al., 2012; Kazhamiakin et al., 2016; Kimura & Nakajima, 2019; Kobeissi et al., 2017; Konstantinidis et al., 2014; Koutsouris et al., 2018; Krommyda et al., 2018; L'Heureux et al., 2017; Laine & Sedano, 2015; Lu, 2018; Madar et al., 2014; Mann et al., 2019; Massoud et al., 2019; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Pargman et al., 2017; Pokric et al., 2015; Poslad et al., 2015; Postolache et al., 2019; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Radeta et al., 2019; Rock Zou et al., 2015; Rowland, 2015; Song et al., 2016; Spyrou et al., 2018; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Wilkowska et al., 2015; Williams et al., 2019; Winnicka et al., 2019)
Long-term Engagement	35	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Alexandre et al., 2019; Bahadoor & Hosein, 2016; Briones et al., 2018; Casals et al., 2017; Ding et al., 2014; Fahlquist et al., 2011; Fernandes et al., 2020; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; García et al., 2017; Gawley et al., 2016; Henry et al., 2018; Kazhamiakin et al., 2016; Kimura & Nakajima, 2019; Konstantinidis et al., 2014; Lapão et al., 2016; Lu, 2018; Massoud et al., 2019; Miglino et al., 2014; Mylonas et al., 2019; Oliver et al., 2018; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Penders et al., 2018; Poslad et al., 2015; Rock Zou et al., 2015; Rowland, 2015; Tan & Varghese, 2016; Tziortzioti et al., 2018; Wilkowska et al., 2015; Williams et al., 2019; Winnicka et al., 2019)
Nonengagement	5	(Gawley et al., 2016; Kimura & Nakajima, 2019; Poslad et al., 2015; Pozzi & Sgardelis, 2016; Williams et al., 2019)

avatars, role playing, or the personification of inanimate objects and content, etc.

(2) Provide incentives to better motivate desired behavior (Banfield & Wilkerson, 2014; Burrows & Blanton, 2016). According to self-determination theory (Deci & Ryan, 2012), people can be motivated by either extrinsic or intrinsic incentives. While the former derives from external sources, e.g., monetary or material rewards, gamification is more frequently associated with the latter. Examples include badges, trophies, levels, and derived social acknowledgment, which originate from the game mechanics and the system itself.

(3) Absorb users into a flow state during an activity, so that they are more willing to adhere to that activity (Constantinescu et al., 2017; Hamari & Koivisto, 2014). A flow state is defined by Mihály Csíkszentmihályi (Csikszentmihalyi & Csikzentmihaly, 1990) as a positive mental state in which a person is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of the activity. It is usually triggered by a good balance between perceived challenges and skills.

(4) Enhance users' performance by correctly setting goals, subgoals, and difficulties (Hamari, 2017; Landers et al., 2017). Goal setting (Locke & Latham, 2013) is a motivation theory explaining the causes of people's performance in tasks and also recognized as an effective strategy of enhancing self-efficacy (Zimmerman et al., 1992).

2.3. IoT-enabled Gamification (IeG)

The earliest attempts to combine IoT and game elements for non-entertainment purposes date back to the 1980s. For example, Honig et al. proposed a rehabilitation system that utilized pressure sensors and television games in 1985 (Honig & Eikelboom, 1985). However, it was during the recent decade that IeG applications have undergone a booming growth, fueled by the unprecedented prevalence of transducer-embedded smart devices and pervasive computing technology. Aside from health, IeG has also been widely adopted in the fields of education, crowdsourcing, smart cities, etc.

The convergence of IoT and gamification is expected to generate more dynamic outcomes for user engagement, interacting with each other in such a way as to offer multiple new benefits, thereby exceeding the sum of their parts. IoT-enabled gamification brings about some synergistic benefits for smart services, for instance, better interactivity leveraging both context awareness and a well-designed gamified mechanism, longer retention of user interest resulting from multisensory feedback and intrinsic motivation, and a lower technical threshold for engaging non-tech-savvy people in a cost-efficient, enjoyable way. None of these can be achieved by exclusively relying on IoT or gamification. Although it is widely believed that IeG can bring about new approaches for smarter and more appealing services, the existing research is scattered across many different application domains, and so, empirical evidence needs to be collected and synthesized through comprehensive literature research in order to guide future practice.

2.4. User Engagement (UE)

Despite its wide usage, the term "user engagement" lacks a consensus definition. There are various definitions proposed in different domains. In computer and information science research, engagement is usually defined as whatever compels people to become engaged and sustain their use of a technical system, for example, "a category of user experience characterized by attributes of challenge, positive affect, endurability, aesthetic and sensory appeal, attention, feedback, variety/novelty, interactivity, and perceived user control" (O'Brien, 2016). In business and service research, engagement is more recognized as an end goal, while user experience is the means to that end. As an example, Brodie defines it as "A psychological state that appears from an important thing (e.g., a brand) due to interactional experiences and creative participation" (Brodie et al., 2011), while other researchers argue that this psychological state involves both attentional (Westgate & Wilson, 2018), attitudinal (Forbes, 2010) and motivational (Van Doorn et al., 2010) factors. In the education field, engagement is defined as a meta-construct that consists of three sub-constructs: cognitive, emotional, and behavioral engagement (Christenson et al., 2012). As a final example, the public governance domain considers engagement as "actions" that "citizens take in order to pursue common concerns and address problems in the communities they belong to" (Zukin et al., 2006).

The varied definitions above reflect the rather complicated and multifaceted nature of user engagement, which likely contributes to the persistent ambiguity surrounding the term. For example, Doherty and Doherty (2018) found, "though engagement is a major theme of research within HCI and related fields, … 65% of publications that address engagement do not provide a definition." Similarly, in the gamification field, varying definitions of engagement that scrutinize the concept from different perspectives have been adopted in the literature. Take a few review papers as examples, in (Darejeh & Salim, 2016) "engagement" depicted a series of behavior of using software, while in another review, the term was more about motivating people (Gupta & Gomathi, 2017). Looyestyn et al. (2017) used "once off" and "sustained" and Stepanovic et al. used (Stepanovic & Mettler, 2018) "long-term" to distinguish the engagement duration. On the other hand, Blok et al. (2021) and Hassan and Hamari (2020) used "family engagement" and "civic engagement" respectively to describe scale feature and social patterns of the engagement. We argue that it actually reflects a community-wide consensus on the multi-construct nature of engagement, as suggested by O'Brien (2016) and O'Brien and Toms (2008), and the literature body encompasses multi-faceted analysis and report, in return, contributes to a more convergent, fine-grained knowledge base. Hence, we argue that an analytical framework need to be constructed to guide our review process, which is supposed to, first, better communicate different aspects and components of engagement construct to the audience and second, reflect the emerging consensus of research community by learning from previous studies in multidisciplinary fields, including but not confined to gamification, cognitive/behavioral psychology (Kappelman & McLean, 1994), sociology (Marino & Presti, 2019), economy, and marketing (Ng et al., 2020). As a result, the following review framework that consists of three respective axes (as shown in Figure 1) was proposed and used in this study:

Cognitive-Behavior Outcome Axis: To evaluate the underlying psychological mechanism of user engagement more precisely, this axis describes the cognitive-behavioral outcome generated by user engagement: (1) **attentional engagement** refers to raising awareness of a certain subject, or drawing users' attention toward it (Schmidt et al., 2016); (2) **attitudinal engagement** refers to shaping/altering users' attitudes toward the subject (Heide et al., 2012); (3) **motivational engagement** refers to incentivizing users' certain behaviors (Martin, 2012); and (4) **behavioral engagement** refers to the actual practice of or involvement in the desired behavior. It is worth noting that the correlation among attentional, attitudinal, motivational, and behavioral engagement is well-recognized in previous research (Li & Lerner, 2013) and manifested as a psychological continuum (da Rocha Seixas et al., 2016). Hence, it is plausible to treat the Cognitive-Behavior Axis as a consistent, progressive process rather than being anchored at one single phase. Engagement may be initialized at the point when a user's attention is captured, while the progress will be intensified as the user's attitude and/or motivation is affected, thus ultimately resulting in his/her behavior change. Therefore, in this research, we intentionally use a continuous interval of cognitive-behavioral phases, e.g., attention and behavior, to better analyze and describe the diverse and dynamic patterns of cognitive-behavioral transition induced by user engagement.

Engagement Stage Axis: According to O'Brien and Toms (2008), user engagement emerged as a process that consists of several different stages "with distinguishable attributes inherent at each stage." The 2nd axis indicates these stages, with the origin of coordinates starting from **non-engagement**. The process of

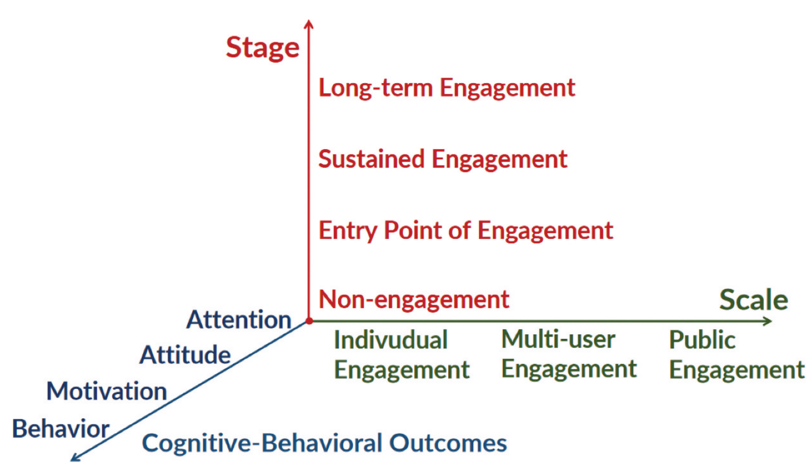

Figure 1. 3-axis user engagement construct.

user engagement initializes when users get involved in the target experience for the first time, i.e., the **entry point of engagement**. As the process continues and the users do not drop out from the current state, it will extend to the stage of **sustained engagement**, which usually takes place in non-transient, sequential behaviors that consist of more than one atomic action. While the **long-term engagement** reflects a stable retention of engagement willingness in the long run, it may notably consist of multiple dynamic cycles of engage–disengage–re-engage behaviors. Moving along the positive direction of the axis, we can observe an increasing engagement intensity, while in the opposite direction from engagement to non-engagement, it instead defines the process known as "disengagement." Disengagement takes place when the users' interest and motivation are not persistently maintained. Also, if users feel that their goal has been achieved or their needs are fulfilled, it is also likely they will break away from the engagement status.

Engagement Scale Axis: Existing studies also suggest that user engagement can be characterized by the user scale that is required to obtain the desired engagement outcomes (Marino & Presti, 2019; Zukin et al., 2006). (1) **Individual Engagement**: Although a massive number of users can be present in the same scenario simultaneously, individual engagement behavior can be achieved by engaging a single user. To simply illustrate, a mobile game application is designed for reminding players to take care of their house plants but also provides some social interaction features like social network sharing or a leaderboard. However, the target behavior of house plant care itself can be achieved by individual engagement either with or without interacting with other users. (2) **Multi-user engagement**: Differing from individual engagement, multi-user engagement usually requires more than one participant and/or stakeholder to be engaged in order to achieve collective goals or group behavior, which may range from family-level to community-level engagement. Examples include a reward posting platform that is shared among family members for learning and using home automation, or a behavior-monitoring digital signage system to increase the hand hygiene compliance of medical staff in ICU. 3) **Public engagement**: Multi-user engagement can further scale up to a crowd/public level, targeting unspecified user groups or the general public. Most crowdsourcing platforms are typical examples of public engagement, as well as a myriad of smart services that are intended to promote positive transitions in public behaviors related to health, transportation, sustainability, etc.

The 3-axis construct is a conclusive and combined result of previous user engagement research. The three axes were selected as they appeared to be the most commonly shared characteristics among existing literature. Therefore, the construct will constitute a significant part of our coding system for thematic analysis, serving as an important framework and index for answering our research questions, which will be introduced in more detail in the following section.

3. Research methodology

3.1. Research questions

This article aims to answer some practical questions around "how to utilize IeG to design and develop engaging smart services and systems" by systematically synthesizing and analyzing evidence from current state-of-the-art research. Figure 2 presents our research questions and how they are organized around some key research subjects.

RQ1. Is IeG an effective approach to achieve UE?

- RQ 1.1 What UE outcomes are reported in existing research?
- RQ 1.2 How do IoT and Gamification elements interplay in current IeG applications?
- RQ 1.3 What empirical evidence is provided in existing research to verify IeG's impacts on UE?
- RQ 1.4 Is there any empirical evidence that IeG is more effective than a traditional approach?

RQ2. If IeG is proved to be effective, what key factors of an IeG system (SF), e.g., usability, accessibility, etc., determine its UE outcome?

- RQ 2.1 What SFs are reported in existing research?
- RQ 2.2 Is there any correlation between a specific SF and certain UE outcomes that can be implied from current literature, e.g., better accessibility results in a larger engagement scale?

RQ3. Are different dimensions of the proposed UE construct interdependent?

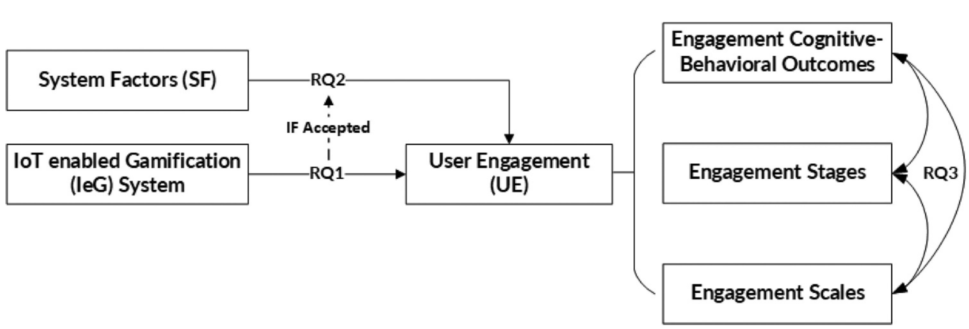

Figure 2. Research questions.

3.2. Review process

A systematic literature review was conducted, based on the Scopus database. We adopted Scopus because it indexes all other potentially relevant databases, e.g., ACM, IEEE, Springer, etc. Since all of these independent databases rely on platform-specific search algorithms and functions, we solidified our search results to be replicable, rigorous, and transparent by focusing on single search engine results. Our search query string was as follows:

(TITLE-ABS-KEY (gamif) OR TITLE-ABS-KEY ("pervasive game") OR TITLE-ABS-KEY ("serious game") OR TITLE-ABS-KEY (games-with-a-purpose) OR TITLE-ABS-KEY ("smart game") AND TITLE-ABS-KEY (iot) OR TITLE-ABS-KEY (internet-of-things) OR TITLE-ABS-KEY ("internet of things") OR TITLE-ABS-KEY ("smart city") OR TITLE-ABS-KEY ("smart cities") OR TITLE-ABS-KEY (sensor-actuator) OR TITLE-ABS-KEY (sensor/actuator)) AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch"))*

The search results were restricted to the categories of (1) conference papers, (2) journal articles, and (3) book chapters, as these categories are able to provide relatively adequate contents for detailed analysis.

Using the aforementioned search string, we acquired a result of 251 hits by the time of October 2020. The authors conducted the first round of screening based on the title and abstract. As a consequence of agreement, 61 results were excluded due to a lack of a clear or significant relationship with IoT and/or gamification; 2 results were identified as mishits, 1 for non-English paper, and 1 for duplication. In addition, there were 7 papers without full-text access. In total, 163 papers remained for the full-content screening.

In the second-round screening, we identified 51 papers as being irrelevant to the topic, 20 as duplication, and 5 papers as literature reviews and surveys. 14 were identified as unqualified papers, which lacked an analyzable description of the research content, approach, and/or result.

In order to avoid omissions as much as possible, we also checked 20 review papers identified in both first and second round screening. 8 papers were excluded due to a lack of relevant review object, for instance, a review on sensing technology and hardware used in gamified systems. 522 references from the remaining 12 reviews were checked then: 91 were neither conference/journal papers nor book chapters, 26 were review or survey papers, 359 were irrelevant to the topic, 28 were duplications, 11 were unqualified for further analysis, 2 were non-English papers, and 2 were without full-text access. As a result, 2 papers were newly added to the review pool.

Finally, we accepted 75 papers and coded them according to the following seven metrics, among which, numbers 3, 4 and 5 allowed multiple tagging.

(1) Bibliometric data: disciplines, publication year, publication type.

Research types: empirical study, research-in-progress, conceptual design. The categorization was based, respectively, on whether a study had both implementation and an analyzable full evaluation, a partial result and on-going progress, or only a conceptual design.

Application domains: health care/wellbeing, sustainability, transportation, economics, energy, education, tourism, industry, smart home/home automation, smart building, entertainment, crowdsourcing, skill training, general purpose.

Engagement scales: individual engagement, multi-user engagement, public engagement.

Engagement stage: entry point of engagement, sustained engagement, long-term engagement, non-engagement.

Cognitive-behavioral outcome: the values were in the form of [x,y], where both x and y came from the set of attention, attitude, motivation, and behavior.

To promote reliability, coding was done by two authors independently, and discrepancies were addressed by discussions between both coders to reach a 100% consensus on the final coding. Centered on our research questions, we further examined the statistical distribution of each metric and investigated the concurrency between some of the metrics, e.g., application domains and different dimensions of user engagement. Aside from the thematic analysis, the authors also carried out in-depth content analysis based on the 36 empirical research sources appearing in the 75 accepted papers. Specific emphasis was also paid to comparatively analyzing the differences between IeG and traditional gamification approaches regarding aspects like application domains, used system factors, effectiveness, etc. The overall results were gathered into domains of bibliometric information, descriptive and empirical results, respectively.

4. Results

4.1. Bibliometric information

4.1.1. Bibliometric distribution

We gathered information from all the papers pertaining to authors, publication years, publication venues, publication types, and disciplines, and examined the bibliometric data of the 75 papers accepted. Except for the year 2020 (the publications of which had not been fully indexed by the time of the literature search), we can conclude that IeG-related publications were relatively scarce before the year 2015, with the earliest paper dating back to 2008. Regarding the publication type, conference papers accounted for 68.0% (51/75) of the whole literature body, 28.0% of articles (21/75), and 4.0% of book chapters (3/75). These results are consistent with our observation that this is a rising research topic and that most studies appeared to be exploratory and preliminary works.

Regarding discipline distribution, we investigated the publication venues, and categorized them into 1) Sociology, 2) Psychology, 3) Computer Science, 4) Information Science, 5) Engineering (referring to a broader sense of engineering other than CS and IS, e.g., energy, mining, electronic engineering, etc.), 6) Management, and 7) Art and Design, based on self-descriptions of the venues. The results showed that more than half of the publication venues fell into multidisciplinary research fields (42/75, 56%). Computer Science (50/75, 66.7%) followed by Information Science (44/75, 58.7%) accounted for the top two dominating disciplines, respectively. Accordingly, it could be implied that while it is still a technology-driven research area, IoT-enabled gamification has traversed a wide spectrum from design, social science, and psychology to management and has manifested the versatile dynamics of typical socio-technical systems.

4.1.2. Typological metrics

Among the 75 accepted papers, 36 papers (48.0%) were identified as empirical research that presented quantified results of in-depth investigations on the effects that different IeG system factors have on user engagement. 29 papers (38.7%) were identified as research in progress, with either no evaluation or only partial evaluation irrelevant to user engagement. The remaining 10 papers (13.3%) were identified as conceptual design work without any actual implementation and evaluation.

4.1.3. Application domains

From the figure above, it can be concluded that the majority of current IeG applications fell into a few specific domains of health care/wellbeing (29.3%, 22/75), sustainability (28.0%, 21/75), and education (20.0%, 15/75), followed by crowdsourcing (9.3%, 7/75), skill training (8.0%, 6/75) and smart home/home automation (8.0%, 6/75). According to a previous literature review (TongKe, 2013), the top six application domains of traditional gamification were education/learning (42.2%), health/exercise (11.8%), software development/design (7.7%), crowdsourcing (6.9%), business/management (6.2%), and ecological/environment behavior (3.9%), respectively. To better compare both results, we merged "education" with "skill training" corresponding to "education/learning," and mapped "sustainability" to "ecological/environment behavior." The results showed that education was the predominant target area of traditional gamification, whereas IeG had a more balanced distribution among different application domains. Specifically, sustainability had a much higher proportion in IeG applications than in traditional gamification. The reason for this might be that IoT has already been widely adopted by energy consumption, environment monitoring, and other sustainability-related fields as a technical infrastructure, thus generating a natural bonding with the gamified applications within this domain. Our empirical research analysis in the next section also supports this insight.

Aside from statistical distribution, the authors also scrutinized whether any correlation existed between different axes of engagement outcomes and certain application domains. The data showed that in the application domains of health care/wellbeing, crowdsourcing, skill training, smart home/home automation, and tourism, 100% of the research tagged related to the final behavior outcome. This was consistent with the reasonable assumption that an actual action is specifically expected in these application domains, instead of stopping with just a change in attitude or awareness. In contrast, the education domain manifested a more even distribution among all four cognitive-behavioral outcomes, probably due to the particularity of education and its width of focus. Similarly, sustainability was also relatively evenly distributed, with a slight inclination toward the behavior outcome, as shown in Figure 3 (Left).

Regarding different engagement scales, a common tendency was seen among the top three application domains of health care/wellbeing, sustainability, and education that over 50% of the research was identified as being related to multi-user engagement, followed by individual engagement at around 40% and the last 10% as public engagement. According to the detailed content analysis, this was because most of the research in these areas involved multiple stakeholders, for instance, therapists and patients, municipal administrators and citizens, teachers and students, etc. The crowdsourcing domain predictably reported the highest percentage of public engagement (57.1%). Since crowd wisdom and the collective knowledge generated by co-innovation progress have been more and more valued at a societal level, the need for a larger scale of citizen participation in all kinds of smart public services can be expected. Accordingly, this will be where future IeG is likely to find its way toward a wider innovation space.

Last but not least, 100% of the research in the health care/wellbeing domain turned out to incorporate the sustained engagement stage, while entry point of engagement and long-term engagement accounted for a relatively lower percentage of 22.7% and 31.8%, respectively. According to our content analysis, we believe that this was mainly because most research in the health area aimed at engaging patients in treatment, rehabilitation, or physical exercise. Thus, the corresponding IeG design was focused primarily on each standardized, sustained behavioral session, then a repetitive, long-term engagement. On the other hand, crowdsourcing also possessed an identical consistency of 100% with sustained engagement; however, it manifested a different pattern of a second-highest consistency of 71.4% with the entry point of engagement and the lowest consistency of 28.6% with the long-term engagement. This could imply that instead of a long-term, stable retention of user engagement, this domain looks to drag users' attentions firstly and more critically to

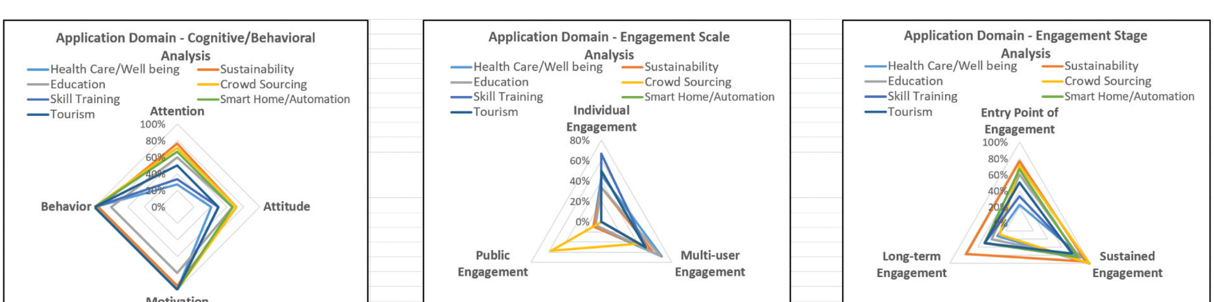

Figure 3. Application domain – engagement outcome correlation.

maintaining their active involvement during a single behavioral session. Generally, the correlation between the application domain and engagement stage was greatly dependent on domain-specific features, and the sustained engagement appeared to be the most involved stage among all domains.

4.2. Descriptive results

4.2.1. What UE outcomes are reported in existing research? (RQ1.1)

In current literature, the reported UE information covers 1) cognitive and behavioral outcomes, 2) the procedural stage of UE, and 3) the population scale of UE.

(1) Cognitive-Behavioral Outcome

The cognitive-behavioral outcomes in the current literature were observed, measured, and described in the literature using a variety of different methods, e.g., by direct observation, system log, self-report questionnaire, etc. In consideration of analysis validity, we adopted an evidence-based method by extracting related keywords, e.g., “behavior,” “interest,” “motivation” etc., and self-claimed statements from the descriptions of research methods and system mechanisms.

If we look at the consistent cognitive-behavioral span instead of the single psychological state, the results showed that nearly half of the papers (49.3%, 37/75) anchored in the interval from Attention to Behavior, and 41.3% (31/75) anchored in the interval from Motivation to Behavior. [Attention, Attitude] and [Attitude, Behavior] had r3 and 4 papers, respectively, in each interval. It can therefore be implied that the psychological outcome of UE is commonly perceived as a coherent progress that traverses multiple states from attentional to behavioral engagement. Particularly, behavioral engagement was reported most frequently in current literature, possibly because behavior change is relatively easier to observe and measure, and is usually the most desirable outcome.

(1) Engagement Stage

The engagement stage information was collected and analyzed from the assertive claims and direct evidence presented in each paper. Sustained engagement was the most mentioned stage (69/75, 92.0%), followed by entry point of engagement (39/75, 52.0%) and long-term engagement (35/75, 46.7%). 66.7% (50/75) of the overall literature involved more than one stage. However, we also noticed that there was only a very limited amount of research (6.7%, 5/75) that mentioned non-engagement. This may be possibly due to the publication bias that researchers tend to focus on the positive effects of user engagement and results, which are seemingly more statistically significant, interesting, or valuable, rather than those that are negative or less so. This observation suggests that issues related to disengagement such as what parts of the approaches lead to an abandonment of the application still remain unexploited space in the field.

(1) Engagement Scale

The engagement scale information (as shown in Table 6) was extracted from the engagement mechanism and relative system design presented in each paper. The multi-user engagement scale accounted for the largest percentage of reviewed papers (58.7%, 44/75), followed by individual engagement (37.3%, 28/75) and public engagement (12.0%, 9/75). 6 papers (Butgereit & Martinus, 2016; Hwang et al., 2012; Mann et al., 2019; Miraz et al., 2015; Oliveri et al., 2019; Van Der Helm, 2008) were considered to involve both individual and multi-user engagement.

4.2.2. How do IoT and Gamification elements interplay in current IeG applications? (RQ1.2)

Current literature shows that traditional gamification approaches, e.g., badges, leaderboards, etc., were reused in IeG application contexts. However, some unique approaches pertaining to IeG were also discovered, and we have particularly delved into how different IoT and gamification elements interplay in forming these new engagement mechanics and dynamics. The identified IeG-specific approaches include:

Gamification of daily things/everything: Traditional gamification is often devised and developed as either PC/mobile applications or in completely non-digitalized forms such as board games. While IoT has endowed daily objects with the ability to interact with people, IeG further extends these “smart things” into “gamified things” by integrating gamification design. With

Table 6. Engagement scale.

Engagement Scale	Amount	Reference
Individual Engagement	28	(Amaro & Oliveira, 2019; Bahadoor & Hosein, 2016; Ben-Moussa et al., 2017; Butgereit & Martinus, 2016; Diego et al., 2018; Ding et al., 2014; Fernandes et al., 2020; Fischöder et al., 2018; Gawley et al., 2016; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Konstantinidis et al., 2014; Lu, 2018; Mann et al., 2019; Massoud et al., 2019; Oliveri et al., 2019; Õunapuu, 2015; Pargman et al., 2017; Penders et al., 2018; Pokric et al., 2015; Quintas et al., 2016; Rock Zou et al., 2015; Spyrou et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Wilkowska et al., 2015; Williams et al., 2019)
Multi-user Engagement	44	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Alexandre et al., 2019; Ardito et al., 2018; Briones et al., 2018; Butgereit & Martinus, 2016; Caivano et al., 2017; Casals et al., 2017; Cherner et al., 2019; Dange et al., 2016; Dessureault, 2019; Fahlquist et al., 2011; Ferreira & Martins, 2018; Fraternali et al., 2017; Gabrielli et al., 2014; García et al., 2017; Garcia-Garcia et al., 2017; Henry et al., 2018; Hwang et al., 2012; Karime et al., 2012; Kimura & Nakajima, 2019; Kobeissi et al., 2017; Konstantinidis et al., 2014; Koutsouris et al., 2018; L’Heureux et al., 2017; Laine & Sedano, 2015; Lapão et al., 2016; Madar et al., 2014; Mann et al., 2019; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Postolache et al., 2019; Radeta et al., 2019; Rowland, 2015; Song et al., 2016; Spyrou et al., 2018; Tziortzioti et al., 2018; Van Der Helm, 2008; Winnicka et al., 2019)
Public Engagement	9	(Büsching et al., 2016; Chen et al., 2017; Kazhamiakin et al., 2016; Kihara et al., 2019; Krommyda et al., 2018; Poslad et al., 2015; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016; Tan & Varghese, 2016)

IoT's evolvement toward an "Internet of People" (Morschheuser et al., 2017) and an "Internet of Everything" (Miraz et al., 2015) where objects, people, and smart services are widely connected, a similar trend for IeG to evolve into a "Gamification of Everything" has also been witnessed in recent literature. Aside from traditional domains like education, health, etc., more extensive and fine-grained gamification application areas have also emerged in both public and private sectors, such as crowdsensing, industry 4.0, smart home/office/cities, and more. As a gamification of everything will provide smarter, more pervasive, and interactive methods for shaping people's behaviors in their daily life, it hence increases the *accessibility* of IeG systems, thus enhancing the channel for engaging users in a more profound and context-aware way.

Embodied experience enhancement: The combination of IoT and gamification also generates new possibilities for user experience augmentation and innovative gameful design. By leveraging various sensors and actuators, IeG is able to provide multisensory, intuitive interactions in a real-time manner. Exemplary usages identified in the current literature include (1) employing physical-movement-based control by detecting gesture, posture, position, and so on (Lapão et al., 2016; Postolache et al., 2019; Wilkowska et al., 2015); (2) providing multisensory stimulus as informative feedback, including but not limited to vibration, thermal sensation, smell, etc. (Karime et al., 2012; Oliver et al., 2018); (3) coupling (1) and (2) with a simulated environment such as extended reality, to create an immersive user experience (Ben-Moussa et al., 2017). Previous studies showed that embodied enhancement can significantly increase overall system interactability and is often associated with somatosensory appeal and immersion, both of which are considered to be able to generate positive impacts on user engagement.

Dynamic User-adapted Incentives: As previously concluded, one major strategy of traditional gamification is to strengthen users' intrinsic motivation via game-like mechanics and dynamics such as leaderboards, challenges, levels, etc. However, current psychological research also points out that there are no "one-size-fits-all" solutions for this strategy to obtain optimal effect and that engagement results may vary greatly from individual to individual. For instance, the flow theory suggests that when a task is too easy or too difficult, it will result in users' quickly dropping-out from the current activity. It can thus be implied that designing a static, general challenge or task may not be enough to engage users with diverse abilities and perceptions, which is indeed often the case. To this end, one of the greatest reinforcements that distinguishes IeG from traditional gamification is that IeG is able to make use of a wide range of contextual information and user behavior data to adjust gamified contents according to each user's condition and preferences in a dynamic, self-adaptive way. Thus, highly personalized and precise incentivization can be achieved. Exemplary usages include (1) deciding rewards and penalties accordingly if a certain user behavior pattern is recognized (Briones et al., 2018; Dange et al., 2016; Rock Zou et al., 2015), (2) adjust gamification mechanics and dynamics, e.g., difficulty, rules, challenges, etc., according to the data of interest, e.g., the user's real-time performance (Kazhamiakin et al., 2016; Oliver et al., 2018), and (3) to project physical reality into virtual representation, e.g., avatars or personified characters, for creating emotional appeal and/or a sense of relatedness (Hwang et al., 2012; Lu, 2018; Papaioannou et al., 2018). Compared with traditional gamification, IeG can better prevent users from disengaging from the target behavior, and thus sustained engagement can be expected.

4.2.3. What System Factors (SF) are reported in existing research? (RQ 2.1)

From current IeG systems and applications, 10 system factors have emerged that manifested a possible correlation with UE outcomes. According to the mechanism or path that each factor takes effect, we further divided the 10 SFs into three categories. (1) *Perceived enablement*, referring to the SFs that allow users to perceive the improvement in their ability to access, understand, and interact with the system. Accessibility and interactability were the two most prominent SFs in this genre. (2) *Perceived appeal*, referring to the SFs that either appeal to users' sensations via visual, auditory, tactile, olfactory stimulus, etc., or appeal to users' emotions like pleasure, empathy, and curiosity. Compared with esthetic and novelty appeals, embodied and immersive appeals were found to be relatively more in favor within the IeG research community, probably because these two SFs were more directly associated with IoT's technical affordance. (3) *Perceived incentive*, referring to heterologous motivations that lead users toward desired behaviors. According to the sources that the different incentives derive from, intrinsic incentives, extrinsic incentives, and social incentives can be seen.

As shown in Table 7, the statistical distribution showed that "Intrinsic incentive" and "Interactability" were ranked as the top two popular SFs in the current literature (85.3%, 64/75 and 84.0%, 63/75 respectively). The prevalent utilization of intrinsic incentives is also consistent with what we have observed from traditional gamification studies (Miranda et al., 2015; TongKe, 2013). However, the empirical evidence also suggested that extrinsic incentives have a better engagement outcome on some occasions, specifically when public or massive behavior transition is targeted. Meanwhile, "Interactability" and the prominent SF of "Accessibility" (73.3%, 55/75) both reflect more of IoT's technical impact on IeG systems. Further discussion about the usage of each factor and their respective effects will be introduced in the next section.

4.2.4. Is there any correlation between SF and UE outcomes? (RQ 2.2)

As shown in Figure 4, intrinsic incentive emerged as the most commonly related SF to all engagement outcomes. While the engagement stage and cognitive-behavior outcome showed a similar distribution over 10 SFs, the engagement scale was relatively different. Specifically, public engagement was found to be closely related to extrinsic incentive and accessibility, individual engagement was associated more with intractability, and multi-user engagement showed an equal distribution over 4 SFs: intrinsic incentive, intractability, accessibility, and social incentive. A reasonable inference is that some SFs may have greater impacts on certain engagement scales. For example,

Table 7. 10 system factors in 3 groups.

Category	System Factor	Explanation	Typical Elements	Reference	Amount
Perceived Enablement	Accessibility	Refers to users' perception of easiness to access certain systems or services	Technical or non-technical barrier, cost and time consumption	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Ardito et al., 2018; Ben-Moussa et al., 2017; Briones et al., 2018; Büsching et al., 2016; Butgereit & Martinus, 2016; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Cherner et al., 2019; Dessureault, 2019; Diego et al., 2018; Ding et al., 2014; Fernandes et al., 2020; Ferreira & Martins, 2018; Fraternali et al., 2017; Gabrielli et al., 2014; García et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Karime et al., 2012; Kazhamiakin et al., 2016; Kimura & Nakajima, 2019; Koutsouris et al., 2018; Krommyda et al., 2018; Lu, 2018; Madar et al., 2014; Mann et al., 2019; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Penders et al., 2018; Pokric et al., 2015; Poslad et al., 2015; Postolache et al., 2019; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Rock Zou et al., 2015; Rowland, 2015; Song et al., 2016; Spyrou et al., 2018; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Wang & Hu, 2017)	55
	Comprehensive-ness	Refers to how well the users are informed about the system and services.	System helper, information assistant	(Ahuja & Khosla, 2019; Amaro & Oliveira, 2019; Casals et al., 2017; Cherner et al., 2019; Fahlquist et al., 2011; Fischöder et al., 2018; Fraternali et al., 2017; Innocent, 2016; Kihara et al., 2019; Laine & Sedano, 2015; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Pokric et al., 2015; Rock Zou et al., 2015; Rowland, 2015; Spyrou et al., 2018; Spyrou et al., 2018; Tziortzioti et al., 2018; Wang & Hu, 2017; Williams et al., 2019)	25
	Interactability	Refers to a broader range of interactive mechanisms that determine the degree and methods of information exchanged between systems and users	Feedback, control flow, contextual awareness	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Alexandre et al., 2019; Amaro & Oliveira, 2019; Ardito et al., 2018; Bahadoor & Hosein, 2016; Ben-Moussa et al., 2017; Butgereit & Martinus, 2016; Casals et al., 2017; Dange et al., 2016; Fahlquist et al., 2011; Fernandes et al., 2020; Fischöder et al., 2018; Fraternali et al., 2017; Gabrielli et al., 2014; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hong & Cho, 2018; Hwang et al., 2012; Innocent, 2016; Karime et al., 2012; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019; Kobeissi et al., 2017; Konstantinidis et al., 2014; Koutsouris et al., 2018; Krommyda et al., 2018; L'Heureux et al., 2017; Lapão et al., 2016; Lu, 2018; Madar et al., 2014; Mann et al., 2019; Massoud et al., 2019; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Pargman et al., 2017; Penders et al., 2018; Pokric et al., 2015; Poslad et al., 2015; Postolache et al., 2019; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Radeta et al., 2019; Rock Zou et al., 2015; Rowland, 2015; Song et al., 2016; Spyrou et al., 2018; Spyrou et al., 2018; Tan & Varghese, 2016; Van Der Helm, 2008; Wang & Hu, 2017; Wilkowska et al., 2015; Williams et al., 2019; Winnicka et al., 2019)	63
Perceived Appeal	Esthetic appeal	Refers to the design style adopted by a system or service that generates positive esthetic experience	Graphical interface, music	(Casals et al., 2017; Fischöder et al., 2018; Garcia-Garcia et al., 2017; Innocent, 2016; Palakvangsa-Na-Ayudhya et al., 2017; Pargman et al., 2017; Pokric et al., 2015; Rock Zou et al., 2015; Rowland, 2015; Van Der Helm, 2008)	10
	Embodied appeal	Refers to the way the interface appeals to or utilizes the user's sensorimotor system	Tactile, olfactory, gustatory stimulus; physical movement based control	(Agyeman & Al-Mahmood, 2019; Alexandre et al., 2019; Amaro & Oliveira, 2019; Ardito et al., 2018; Ben-Moussa et al., 2017; Butgereit & Martinus, 2016; Chen et al., 2017; Fischöder et al., 2018; Gabrielli et al., 2014; Gawley et al., 2016; Hong & Cho, 2018; Hwang et al., 2012; Karime et al., 2012; Kihara et al., 2019; Kobeissi et al., 2017; Konstantinidis et al., 2014; Krommyda et al., 2018; Laine & Sedano, 2015; Madar et al., 2014; Miglino et al., 2014; Monge & Postolache, 2018; Oliver et al., 2018; Palakvangsa-Na-Ayudhya et al., 2017; Pargman et al., 2017; Postolache et al., 2019; Pozzi & Sgardelis, 2016; Radeta et al., 2019; Song et al., 2016; Spyrou et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Wilkowska et al., 2015)	32

(*Continued*)

Table 7. (Continued).

Category	System Factor	Explanation	Typical Elements	Reference	Amount
	Immersive appeal	Refers to user's feeling of being transported to another environment in a metaphorical or immersive way.	Avatar, personification, narrative, role playing	(Alexandre et al., 2019; Ben-Moussa et al., 2017; Casals et al., 2017; Chen et al., 2017; Cherner et al., 2019; Fahlquist et al., 2011; Fischöder et al., 2018; Garcia-Garcia et al., 2017; Henry et al., 2018; Kihara et al., 2019; Konstantinidis et al., 2014; Krommyda et al., 2018; Lu, 2018; Madar et al., 2014; Oliveri et al., 2019; Õunapuu, 2015; Pargman et al., 2017; Postolache et al., 2019; Rock Zou et al., 2015; Rowland, 2015; Song et al., 2016; Wang & Hu, 2017; Williams et al., 2019)	23
	Novelty appeal	Refers to providing new contents in order to acquire users' sustained curiosity and interests.	Time-limited tasks or challenges, downloaded contents, patches	(Ahuja & Khosla, 2019; Amaro & Oliveira, 2019; Innocent, 2016; Kazhamiakin et al., 2016; Poslad et al., 2015; Rowland, 2015)	6
Perceived Incentive	Social incentive	Refers to the incentives that users can gain from direct or indirect interaction with others.	Leaderboard, competition, collaboration, feeling connected with others	(Ahuja & Khosla, 2019; Ardito et al., 2018; Bahadoor & Hosein, 2016; Butgereit & Martinus, 2016; Caivano et al., 2017; Casals et al., 2017; Dange et al., 2016; Dessureault, 2019; Diego et al., 2018; Fahlquist et al., 2011; Ferreira & Martins, 2018; Fraternali et al., 2017; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hwang et al., 2012; Innocent, 2016; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019;Kobeissi et al., 2017; L'Heureux et al., 2017; Laine & Sedano, 2015; Lapão et al., 2016; Madar et al., 2014; Mann et al., 2019; Miglino et al., 2014; Mylonas et al., 2019; Oliveri et al., 2019; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Penders et al., 2018; Pokric et al., 2015; Poslad et al., 2015; Quintas et al., 2016; Radeta et al., 2019; Rowland, 2015; Tziortzioti et al., 2018; Van Der Helm, 2008; Wang & Hu, 2017; Winnicka et al., 2019)	42
	Intrinsic incentive	Refers to the incentives that users can gain from the internal mechanism of the systems or services	Badges, goals, challenges, achievements	(Agyeman & Al-Mahmood, 2019; Ahuja & Khosla, 2019; Alexandre et al., 2019; Amaro & Oliveira, 2019; Ardito et al., 2018; Bahadoor & Hosein, 2016; Ben-Moussa et al., 2017; Briones et al., 2018; Butgereit & Martinus, 2016; Caivano et al., 2017; Casals et al., 2017; Chen et al., 2017; Dange et al., 2016; Dessureault, 2019; Ding et al., 2014; Fahlquist et al., 2011; Ferreira & Martins, 2018; Fischöder et al., 2018; Fraternali et al., 2017; Gabrielli et al., 2014; García et al., 2017; Garcia-Garcia et al., 2017; Gawley et al., 2016; Henry et al., 2018; Hwang et al., 2012; Karime et al., 2012; Kazhamiakin et al., 2016; Kihara et al., 2019; Kimura & Nakajima, 2019; Konstantinidis et al., 2014; Koutsouris et al., 2018; Krommyda et al., 2018; L'Heureux et al., 2017; Laine & Sedano, 2015; Lapão et al., 2016; Madar et al., 2014; Mann et al., 2019; Massoud et al., 2019; Miglino et al., 2014; Monge & Postolache, 2018; Mylonas et al., 2019; Oliver et al., 2018; Oliveri et al., 2019; Õunapuu, 2015; Palakvangsa-Na-Ayudhya et al., 2017; Papaioannou et al., 2018; Pargman et al., 2017; Penders et al., 2018; Pokric et al., 2015; Poslad et al., 2015; Postolache et al., 2019; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016; Quintas et al., 2016; Radeta et al., 2019; Rock Zou et al., 2015; Song et al., 2016; Spyrou et al., 2018; Spyrou et al., 2018; Tan & Varghese, 2016; Tziortzioti et al., 2018; Wilkowska et al., 2015; Williams et al., 2019; Winnicka et al., 2019)	64
	Extrinsic incentive	Refers to the external incentives that users can gain from outside the mechanism of systems or services.	Monetary reward, in-kind reward, coupons	(Briones et al., 2018; Büsching et al., 2016; Caivano et al., 2017; Diego et al., 2018; Ding et al., 2014; Fernandes et al., 2020; Ferreira & Martins, 2018; Fraternali et al., 2017; García et al., 2017; Palakvangsa-Na-Ayudhya et al., 2017; Poslad et al., 2015; Pouryazdan et al., 2017; Spyrou et al., 2018; Tan & Varghese, 2016)	14

individual engagement predictably involved less social incentive compared with multi-user engagement. Surprisingly, public engagement appeared to involve the least social incentive. After content analysis, we argued that one possible reason may be that the current IoT infrastructure is not yet sufficient to support massive social interaction, specifically with an unspecified majority of people involved. A fully fledged information infrastructure and corresponding socio-technical solutions are prerequisites for supporting large-scale social interaction, among which the Social Internet of Things is considered as one of the promising directions (Atzori et al., 2012). The Social IoT is still under development but has already aroused great interest from large companies, such as Facebook and Google (Rho & Chen, 2018). As technology matures, IeG that can support public engagement may become a new hot area. In this literature review, we identified three papers that have researched

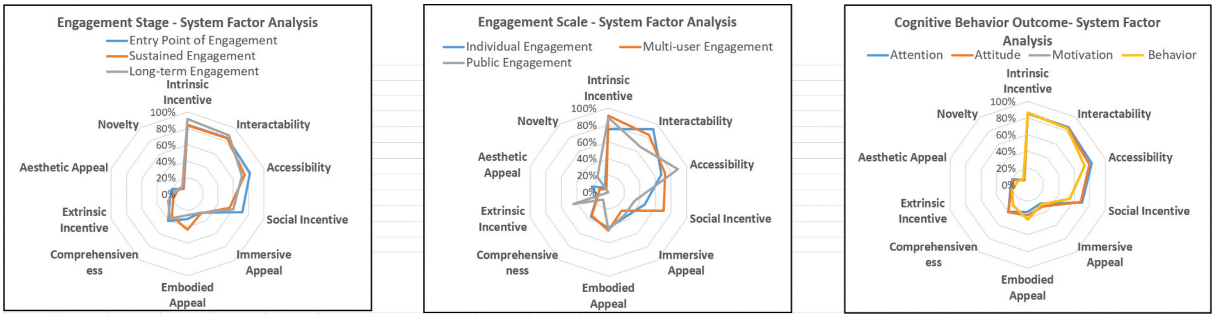

Figure 4. Engagement outcome –system factor correlation.

this topic from either theoretical or lower layer technology aspects (Kazhamiakin et al., 2016; Kihara et al., 2019; Poslad et al., 2015).

4.2.5. Are different dimensions of the proposed UE model interdependent? (RQ3)

As shown in Figure 5 (left), research on public engagement showed more interest in attention and attitude than individual and multi-user engagement research. This phenomenon is consistent with the Nudge Theory, which is being actively incorporated by many governments into their public engagement strategies. "Nudge" is a concept suggested by economist Richard Thaler and legal scholar Cass Sunstein (Thaler & Sunstein, 2010), which proposed positive reinforcement and indirect suggestions as ways to influence people's behavior and decision making. Behavior change on a population level is never an easy task. The nudge theory argued that a more applicable strategy is to draw people's attention or strengthen their attitude instead of directly regulating their behavior, by better designing and presenting a "choice architecture" (Brown, 2012; Vetter & Kutzner, 2016).

Regarding the correlation between engagement stage and cognitive-behavioral outcome, we noticed that the consistency rate between the entry point of engagement and the [attention, attitude] interval, as well as long-term engagement and [motivation, behavior], both reached an extremely high percentage of 100%. The former is consistent with our preconception that the entry point of engagement and the cognitive stage of human attention are interdependent. While the latter, on the other hand, indicates that all the research involving long-term engagement also involved behavior changes at the same time. However, not all the research targeting behavior changes were aimed at long-term engagement, and this implies a more intensive, but one-way concurrent relation between long-term engagement and the behavioral phase, in contrast to the other engagement stages.

Regarding the correlation between engagement stage and scale, as shown in Figure 5 (Right), sustained engagement appeared to be the most related stage to all three engagement scales (92.9% of individual engagement, 93.2% of multi-user engagement and 88.9% of public engagement respectively). Moreover, public engagement manifested the closest relationship with the entry point of engagement (66.7%), in comparison to individual engagement (50.0%) and multi-user engagement (47.7%).

4.3. Empirical results

Among all the reviewed papers, 36 papers were spotted as empirical studies with full implementation and detailed evaluation results. To further investigate IeG's efficacy and effectiveness over user engagement, we particularly analyzed the empirical evidence collected from each empirical study, and a detailed analysis can be found in Appendix A. Some preliminary answers to the research questions are provided below.

4.3.1. What empirical evidence is provided to verify IeG's impacts on UE? (RQ 1.3)

(1) *Evidence of improved cognitive-behavioral engagement outcome.* 6 papers evaluated attentional engagement, and IeG's improvement in piloting users' attentions or awareness toward a system and/or system-encouraged activities was observed. Specifically, 3 papers reported that users' attentional engagement increased after using IeG systems, and 1 paper reported that the IeG system had better engagement outcome compared with the traditional application. We also noticed that current methods to measure attentional outcomes were mostly manual approaches like self-report questionnaires, psychometric tests, user interviews, and interaction record analysis. Although it is technically feasible to automate the procedure by adopting psycho-physiological measurements like eye-tracking, EEG sensing, etc., this method is still greatly restricted by issues such as cost and accuracy in real practice.

20 papers evaluated attitudinal engagement, with 18 reporting positive effects from different aspects, 1 reported no significant difference, and 1 reported a negative result. Positive results include (1) general positive feedback or welcome attitude after interacting with IeG systems (7 papers); (2) perceived system usefulness, effectiveness, or satisfaction (8 papers); (3) enjoyable or attractive user experience (3 papers); and (4) perceived positive changes in attitudes/opinions (1 paper). The only negative result was reported because the system-encouraged behavior was considered irrelevant or unfeasible. Similar to attentional engagement, the measurement for attitudinal engagement included self-report questionnaires, psychometric tests, and user interviews.

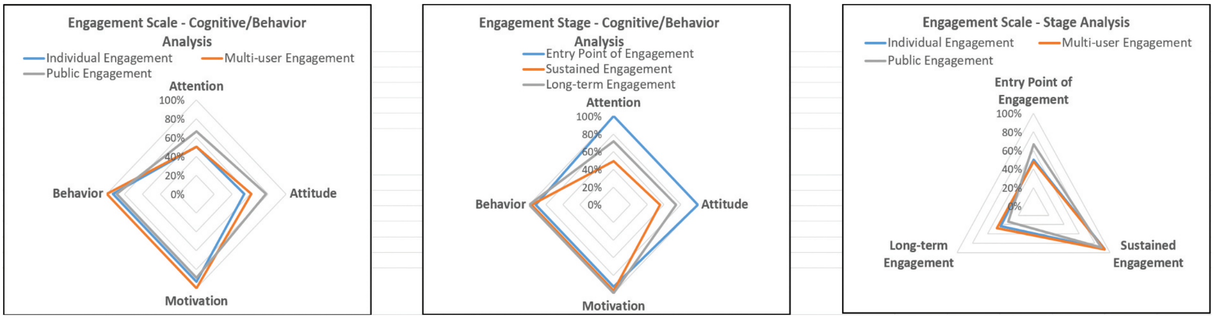

Figure 5. Engagement outcome pairwise correlation.

9 papers evaluated motivational engagement. As a result, IeG was reported to be able to increase and/or maintain users' motivation to conduct and/or repeat a target behavior that was encouraged by the system. 1 paper reported that the more times the IeG system was used, the stronger users' motivation grew. Self-report questionnaires, psychometric tests, and expert ratings were utilized to evaluate the motivation engagement outcome.

21 papers evaluated behavioral engagement, among which 20 papers reported positive behavioral outcomes via pre-post comparison or control group experiment, and 1 paper reported no significant changes before and after using the IeG system. Reported effects included performance improvement of existing behavior (13 papers), frequency changes (10 papers), and new behavior/habit forming (4 papers). Target behaviors ranged from work performance and learning to sustainable behavior. A large proportion of the studies leveraged IoT to recognize and monitor human behavior as well as the surrounding environment, hence a system log-based evaluation became the most utilized measurement method (21 papers), followed by self-report questionnaires (19 papers), user interviews (12 papers) and observations (6 papers).

(1) *Evidence of engagement stage applicability*. 22 papers described IeG systems that involved the entry point of engagement applicability, i.e. a successful direction of users' attentions toward the use of system and/or system-encouraged attitude/behavior. 36 papers described sustained engagement applicability, i.e. completion of an uninterrupted operation that requires continuous use of the system. 26 papers described long-term engagement applicability, i.e. the repetitive use of the system and/or long-term retention of system-encouraged attitude/behavior. In addition, 5 papers involved non-engagement, i.e. drop-out from using the system, neglect or opposition of system-encouraged attitude/behavior.
(2) *Evidence of engagement scale applicability*. Regarding the engagement scale, 10 papers targeting individual engagement had sample sizes for user experiments ranging from 6 to 504 participants. 28 papers targeting multi-user engagement had sample sizes ranging from 4 to 1,819 participants. 6 papers targeting public engagement had sample sizes from 4 to 15,600 participants. With varying degrees of effectiveness, the IeG approach was reported as applicable to use on a wide range of user scales, as well as diverse social interaction patterns.

4.3.2. Is IeG more effective than a traditional approach? (RQ 1.4)

Since IeG is a newly emerging method for user engagement, there is still insufficient comparative analysis that systematically studies the differences between IeG and its parallel approaches. Yet, we managed to plot several papers that compared IeG's user engagement effects with its traditional counterparts, such as general systems without gamification and gamified applications. In Chen et al. (2017)'s user experiment, participants were asked to use both IeG and mobile applications, then give feedback using a Likert scale. The results showed that IeG was considered both more attractive and enjoyable. Lu (2018) compared IeG and non-IoT gamification's effects on promoting daily energy saving behaviors, and found that the IeG application reduced energy consumption by 37% more than the non-IoT gamified application on average. Miglino et al. (2014) compared three different psycho-pedagogical methods with their respective IeG-enhanced versions, and in the third study, a control group experiment was used. The results showed that while the learning performance of the participants who used the IeG systems manifested no significant difference from those who used the traditional one, most participants agreed that the user experience of the IeG system was more socializing and enjoyable, hence more engaging. In addition, Oliver et al. (2018) conducted an expert evaluation and concluded that the integration of IoT was able to magnify the performance of general gamified telerehabilitation systems.

In general, the effects of IeG-enhanced systems were reported as identical or above their traditional counterparts from different perspectives and application domains.

4.3.3. Is there any correlation between a specific SF and certain UE outcomes? (RQ 2.2)

During this review, we identified a limited amount of scattered empirical evidence, indicating that specific SFs are correlated to certain UE outcomes, either directly or indirectly. For example, in Bahadoor's study (2016), experiment participants reported that social seed (social incentive) and discount rewards (extrinsic incentive) were the two SFs they perceived most useful for keeping using the IeG system and retaining safe driving behaviors such as obeying speed limits, stable driving without sudden lane changes or speed-up/down, etc. (long-term engagement). Alexandre et al. (2019) used a control group experiment and pre-post comparison and found that imparting security and privacy-related knowledge (comprehensiveness) helped raise smart watch users' awareness of privacy protection. However, the authors also pointed out that although some users understood how to protect their privacy and admitted the importance of this issue, they consciously chose to ignore it due to inconvenience (accessibility) and other reasons. This showed that comprehensiveness, i.e., users' understanding about the system and/or system-promoted behavior, can contribute to the cognitive outcome at awareness and/or attitude levels. However, if the target is behavior change, then it may also require the incorporation of other SFs to overcome the "attitude-behavior gap" (Fazio & Roskos-Ewoldsen, 2005). In (Casals et al., 2017), a smart serious game for promoting energy saving was proposed. Aside from providing users with energy saving tips (comprehensiveness), intrinsic incentives like scores and missions were also used. It was found that players who achieved higher scores and completed more missions in the game turned out to also have better electricity saving results, which implies that intrinsic incentives can act as an important impetus to putting knowledge into practice ([motivation, behavior]). Further research suggested that SFs like social incentives (team-based competition), embodied appeal (physical interaction), interactability (adaptive contextual awareness), etc., may have a compound impact on behavioral outcome (Hwang et al., 2012; Lapão et al., 2016; Lu, 2018). To note that, Poslad (Poslad et al., 2015) reported that the use of challenges and rewards has the potential to change users' behaviors, but they need to be individualized to achieve an optimal outcome, and the effects are usually highly context-dependent. Also, a social network feature was perceived as useful as it supported information sharing and exchanging, however, it did not necessarily contribute to shifting users' behavior itself. Generally, it can be concluded that even for the same SF, the final UE outcome it generates depends on both what specific form it takes, as well as how it incorporates with other SFs to constitute the overall IeG system mechanics and dynamics.

Many other studies evaluated only the general user experience and usability, without breaking down elaborate system factors. It is also noteworthy that the correlation revealed by some empirical evidence may not necessarily be limited to a causal relationship. For example, simple concurrency or an interrelated relationship was often found in many education and skill training IeG systems, where knowledge impartation often acts as both a system factor for improving UE and the system-encouraged behavior itself. To briefly sum up, it is still too early to make an assertion about the effectiveness of each system factor and their combined effects, until a more solid validation is made. Therefore, more future studies based on rigorous experiments and empirical evidence are needed to generate reliable knowledge for guiding engaging IeG system design and development.

5. Conclusion and discussion

As a brief conclusion, IeG has manifested great potentials as an emerging UE approach, the instantiation of which will be of value for developers and designers across diverse application domains, including but not limited to sustainability, healthcare, education, industry 4.0, smart cities, and public services.

5.1. Limitations

There are a few limitations related to this work. To ensure the reliability of the thematic analysis, structured codes and an inter-coder method were adopted to determine the final coding. However, possible bias may still exist due to the coder subjectivity. Also, to obtain a controllable amount of query results, the authors intentionally specified the query string using explicit expressions of IoT and gamification-related keywords. However, it was inevitable that papers with implicit or domain-specific expressions in their titles and abstracts, e.g., "embodied interaction," "edutainment," etc., were excluded from this review.

5.2. Major findings

In this study, 75 papers regarding IeG, among which 36 were identified as empirical research, were analyzed systematically according to the proposed 3-axis UE model, respectively: cognitive-behavioral outcome, engagement stage, and engagement population scale. Our major findings are concluded below.

First, although existing literature has covered most research space defined by the aforementioned three axes, mainstream studies tend to focus on motivational and behavioral engagement, sustained engagement, and multi-user engagement. Empirical evidence showed that well-designed IeG systems can generate significant impacts on user engagement. This finding is allied with previous literature reviews on gamification and engagement in other fields (Darejeh & Salim, 2016; Hassan & Hamari, 2020; Looyestyn et al., 2017). However, most gamification literature reviews discussed "engagement" as a whole or from one exclusive aspect. As an example, Stepanovic et al. argued that "long-term engagement … is too often neglected" (Stepanovic & Mettler, 2018). To this end, this article contributes to the state of the art by explicating current literature body based on a multi-faceted analytical framework. Specifically, the results showed that better behavioral performance, longer retention, and a larger user population can be expected.

Second, as IoT and gamification merged into a new continuum, several novel approaches have emerged, including 1) gamification of daily things/everything, 2) embodied experience enhancement, and 3) dynamic user-adapted incentives. Existing research showed that these hybrid methods presented greater behavior improvement, and they were better accepted by users or considered more effective by domain experts. There was also unique research that conducted control group experiments or evaluations to comparatively study the differences between IeG and existing solutions. However, more empirical evidence is needed before we can draw a conclusion that the user engagement outcome of IeG has exceeded that of traditional gamification.

Last but not least, 10 IeG system factors have manifested possible correlations with engagement outcome. We further divided these into three categories, namely perceived enablement, perceived appeal, and perceived incentives. Among all, accessibility and interactability in the group of perceived enablement, embodied and immersive appeal in the group of perceived appeal, as well as intrinsic incentive in the group of perceived incentives turned out to be the most accentuated SFs in each group, respectively. Empirical evidence also suggested that certain SF groups have stronger effects on specific engagement outcomes, e.g., perceived incentive was more associated with motivational and behavioral engagement, while perceived appeal was more associated with attentional and attitudinal engagement. A few previous literature studies also investigated specific uses of gamification elements, e.g., reward, goals, and points. However, the results were highly domain/application specific and not neccesarily aligned. For example, Looyestyn et al. found that gamification systems for online program engagement favor leaderboard (one of the social incentives) the most (Looyestyn et al., 2017), while Hassan et al. found that gamification systems for civic engagement prefer points (one of the intrinsic incentives) to leaderboards (Hassan & Hamari, 2020). In IoT-enabled gamification systems, the intrinsic incentives were found the most popular SF, which was closer to Hassan et al.'s finding. Similar conclusions can also be drawn by comparing the uses of other gamification elements like avatar, story, goal setting, and challenge, etc (Blok et al., 2021; Darejeh & Salim, 2016; Gupta & Gomathi, 2017; Hassan & Hamari, 2020; Looyestyn et al., 2017; Stepanovic & Mettler, 2018); however, the detailed discussion was not included in this paper.

5.3. Discussions for future research

As a rising multidisciplinary research field, IeG still has plenty of unexploited areas. To establish a comprehensive theoretical and practical knowledge base, there remain several critical issues to be addressed in future work:

1) *Accessibility may become the first bottleneck for IeG*. In comparison to IeG applications that involve users at family and community levels, most applications that claimed to target a massive public actually adopted individual-oriented approaches. Consequently, this made the accessibility of each and every target user a prerequisite before any of the engagement factors takes effect. As an undesired result, many non-commercial applications and services, like those mentioned in studies (Poslad et al., 2015; Pozzi & Sgardelis, 2016), were forced to confront a dilemma: How to make their systems "commercially successful" to gain a large enough user base in the first place? To this end, Gawley et al. (2016) provided an example to balance commercialization and the promotion of target behavior, in which a mobile game based on smart bracelet data was developed to encourage wearers' daily physical exercise. Interestingly, the game was not only confined to smart bracelet owners but also could be downloaded and played by general mobile users. Disentangling the gamified contents from those system components that may become hurdles and therefore eliminate possible users is an approach that is not only able to extend the accessibility among all of the potential audience but also one that increases the possibility to attract and direct non-target users' interest toward the desired attitude/behavior that the system promotes. This is particularly true for those IeG systems coupled with smart devices, the hardware availability of which may take priority over any other technical barriers. Büsching et al. (2016) and Tan and Varghese (2016) tried to tackle this problem by distributing low-cost devices (an RFID-embedded key holder) or installing the equipment (a smart cycling machine) in a publicly accessible place. While it may be unrealistic or unaffordable on some occasions to deploy a real physical implementation, simulation using a miniature system (Cherner et al., 2019; Õunapuu, 2015) or in a fully virtualized form (Oliveri et al., 2019; Wang & Hu, 2017) may be a cost-efficient way to enhance public accessibility.

2) *Data intensive Gamification*. Distinct from traditional gamification, IeG systems are usually accompanied by massive data generated by numerous sensor nodes and smart objects. It entails a sophisticated mechanism to handle and better exploit especially highly sensitive personal data collected from the personal area network (PAN) and body area network (BAN). On one hand, the existing mechanics, dynamics and even esthetics applied to gamified applications will possibly become driven by the data as presented in the previous discussion of RQ1.2. By further measuring and analyzing users' instantaneous physical/mental status via biofeedback, it provides factual evidence complementary to self-reported results and helps understand questions like when and what makes users disengage, etc., thus strengthening the validity of engagement studies as a whole. On the other hand, gamification can actually take place in each and every stage in the life cycle of user data, e.g., in data generation which is already familiarized by various crowdsourcing/sensing IeG systems (Chen et al., 2017; Pouryazdan et al., 2017; Pozzi & Sgardelis, 2016). While data processing has overlaps with data generation, it emphasizes more on manually tagging or categorizing data (Krommyda et al., 2018; L'Heureux et al., 2017), which is not necessarily generated by the users themselves. Data representation in IeG usually refers to extracting useful information from voluminous raw data and representing it in a meaningful and gameful way, for example, in the form of personified data (Oliver et al., 2018; Papaioannou et al., 2018) or data visualization using AR/VR (Pokric et al., 2015). IeG systems involving data management and consumption also widely exist, and an exemplary application is the gamified Building Information Modeling (BIM) system. Rowland (2015) proposed using a Multiuser-Online-Game-like paradigm to maintain BIM data in an open, real-time manner, which is identical to the digital twin of an architecture in a sense. It is noteworthy that like any other data intensive system, IeG is also facing security and privacy issues, however, deeper discussions of this fall outside our research scope in this article.

3) *IeG-mediated Social Game/Gamification*. The interplay between IoT and gamification has also diversified the interaction patterns among users, and some unique trends have emerged from the current literature. Firstly, social robots were found to be utilized in traditional domains like education, where the term "edutainment robot" was coined (Miglino et al., 2014; Spyrou et al., 2018). It can be foreseen that besides humanoid robots, more and more polymorphic robots like drones and such ones will certainly become part of future IeG systems in diverse application scenarios. However, how to provide a "meaningful" experience that is functionally, socially and affectively associated with human users, is a question beyond what IoT can answer alone. Second, embodied interaction based on psycho-physiological/behavioral sensing has provided an alternative channel other than traditional verbal interaction. For instance, Mann et al. (2019) proposed a system for multiple players to compete using visualized brainwave signals. In Hwang's study (2012), an exergame used smart exercise machines, e.g., a treadmill, to detect a runner' speed. A player could collaborate with his/her teammate by adjusting the running pace, and then further compete with other teams. Finally, hybrid social experience will further blur the boundaries between online and offline users (Fahlquist et al., 2011), as well as between virtual and physical reality (Hwang et al., 2012). As social networks have rapidly penetrated people's daily life, many IeG systems also try to leverage its network effect as an entry for initializing engagement, or as reentry for repetitive engagement. However, as media by which people's physical, digital and social existences coincide social networks' potential to deliver a coherent, hybrid user experience has not yet been fully exploited. Moreover, by incorporating social sensing and mining, it is possible to comprehend complicated social context. Together with physical environment data extracted by IoT sensors, more context-aware, target-oriented engagement effects can be expected.

Notes

1. https://ec.europa.eu/digital-single-market/en/policies/internet-things
2. https://ec.europa.eu/research/swafs/index.cfm?pg=policy&lib=engagement
3. https://www.gallup.com/workplace/229424/employee-engagement.aspx
4. https://www.smartcitiesworld.net/news/news/citizen-engagement-is-key-to-smart-city-success-2685

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Appendix A. Detailed results of each empirical research

Reference Number	Domain	Participants	Cognitive-behavioral Engagement Outcome	Engagement Scale	Engagement Stage	Engagement Measurement	System Factors	Factor measurement
(Agyeman & Al-Mahmood, 2019)	Health Care/ Well being	8	Attitude: Most participants agree that IeG is useful and feasible to help in the rehabilitation process of stroke patients	Multi-user Engagement	Period of Sustained Engagement, Long-term Engagement	questionnaire		
(Ardito et al., 2018)	Tourism	14		Multi-user Engagement	Period of Sustained Engagement		General usability	SUS, NPS, NASA-TLX
(Bahadoor & Hosein, 2016)	Skill training	6	Attitude: users reported 100% positive feedback, some features are reported to be useful	Individual Engagement	Period of Sustained Engagement, Long-term Engagement	self-report, questionnaire	Social incentive: 100% participants report social feed and discount reward are useful, Interactivity: 67% participants report that interactive map is useful	self-report
(Wilkowska et al., 2015)	Health Care/ Well being	64	Attitude: users report that the system is usefulMotivation:The more users use the system, the stronger the willingness to continue using	Individual Engagement	Period of Sustained Engagement, Long-term Engagement	self-report, system log	Social incentive: need for achievement is reported as a determinant of behavior in multiple regression analysis,	questionnaire, system log
(Briones et al., 2018)	Sustainability	1819	Behavior: recycled waste amount increased 17.2% in pre-post comparison (performance), participation increased by 32.2% (frequency)	Multi-user Engagement	Point of Engagement, Long-term Engagement	system log		
(Casals et al., 2017)	Sustainability	80 (control group 40, experiment group 40)	Behavior: experiment group showed statistically more energy saving in experiment-control group comparison (Performance)	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	system log	Intrinsic incentive: Tenants who achieved higher game scores and completed more missions achieved higher electricity savings	system log
(Chen et al., 2017)	Crowd Sourcing	4	Attitude: participants report IeG is more enjoyable and attractive than traditional app	Public Engagement	Point of Engagement, Period of Sustained Engagement	self-report, questionnaire		
(Dange et al., 2016)	Skill training	Unknown	Behavior: better driver behavior pattern is detected after using IeG system (performance)	Multi-user Engagement	Period of Sustained Engagement	system log		
(Dessureault, 2019)	Industry	Unknown	Behavior: 30–76% productivity improvement in pre-post comparison (performance), expected operation increased 233% (frequecy)	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement	system log		
(García et al., 2017)	Sustainability	18	Behavior: energy consumption per day decreased 6.6% during the 30 days experiment (performance)	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	system log		
(Henry et al., 2018)	Education	22 (Control group 11, experiment group 11)	Behavior: experiment group has 55% more response rate in experiment-control group comparison (performance)	Multi-user Engagement	Point of Engagement, Long-term Engagement	system log		
(Hwang et al., 2012)	Health Care/ Well being	32/11	Attitude: participants have positive feedback and agree that the system is helpful to excercise behavior: more conversation observed in proposed system than standard level (frequency)	Individual Engagement, Multi-user Engagement	Point of Engagement, Period of Sustained Engagement	video based behavior analysis, interview	Immersive appeal: participants strongly agreed that physical interaction game helped them better immersed in excercises	interview
(Karime et al., 2012)	Health Care/ Well being	21(20 healthy users, 1 patient)	behavior: patients have overall better performance to finish Rehabilitation tasks during the 14-days experiments (performance)	Multi-user Engagement	Period of Sustained Engagement	system log		

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Reference Number	Domain	Participants	Cognitive-behavioral Engagement Outcome	Engagement Scale	Engagement Stage	Engagement Measurement	System Factors	Factor measurement
(Kazhamiakin et al., 2016)	Sustainability, Transportaion	300 (100 active participants, 36 survey respondents)	attitude: 63% participants report the proposed system changed their mobility habit motivation: 81% participants intend to keep the new habits in the future behavior: sustainable mobility behavior increased (frequency), IeG system has better acceptance of recommendation than traditional system	Public Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	self-report, system log	Novelty appeal: Behavior frequency changed when challenge theme changed,	system log
(Kihara et al., 2019)	Education	4	attention: privacy awareness increased from 2.75 to 3.25 averagely in 5-point likert scale; attitude: anti-surveillance attitude increased from 3.25 to 4.25 averagely;	Public Engagement	Point of Engagement	interview, self-report		
(Lapão et al., 2016)	Skill training	4	attention: increased compliance awareness among participants is reported; behavior: increased compliance behavior is reported (frequency);	Multi-user Engagement	Point of Engagement, Long-term Engagement	interview		
(L'Heureux et al., 2017)	Crowd Sourcing, Smart Building	86 gaming actions	behavior: participants reported the system changed their wasteful consumption habits (performance),72.6% actions in the system helped to crowd-sourced data labeling (frequency).	Multi-user Engagement	Period of Sustained Engagement	interview, system log		
(Lu, 2018)	Smart Home/ Home Automation, Sustainability	22 for each simulation test	Behavior: energy consumption decreased 16.21–37% (performance)	Individual Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	system log	Accessibility: adaptive contextual awareness feature had impact on behavior	system log, interview
(Miglino et al., 2014)	Education	Test I: 257 students, 2 children,10 teacherTest II: 1 girl with multiple disabilitiesTest III: 52 students	attitude: participants prefer IeG than traditional method behavior: no statistical difference was found when comparing learning performance in IeG system and system using traditional approach	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	observation, interview	Immersive appeal: children are observed to be more involved in learning process,Social incentive: learners report more fun and socializing perception	observation, self-report
(Mylonas et al., 2019)	Education, Sustainability	106 students for workshop in total, 7 teachers for questionnaire, 5 teachers for interview	attitude: 84% and 94% students in two workshop report the system is engaging, 98% and 96% report the system is useful behavior: learning performance	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	self-report, questionnaire	Social incentive (Competition, social network) and Interactability (awareness, recommendation) are hypothesized to strengthen engagement, however no empirical evidences are provided	not reported
(Oliver et al., 2018)	Health Care/ Well being	20	attitude: expert satisifaction scored 8.76/10	Multi-user Engagement	Period of Sustained Engagement, Long-term Engagement	Questionnaire; Expert Rating;		
(Oliveri et al., 2019)	Education, Industry	11 in total (4 in final test)	attitude: participants report interests in the system behavior: increased learning outcomes in pre-post comparison (performance)	Individual Engagement, Multi-user Engagement	Period of Sustained Engagement	interview	General usability	questionnaire
(Palakvangsa-Na-Ayudhya et al., 2017)	Education, Economic	Unknown	Motivation: Expert admit that the system can motivate children to start money saving	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	expert rating		

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Reference Number	Domain	Participants	Cognitive-behavioral Engagement Outcome	Engagement Scale	Engagement Stage	Engagement Measurement	System Factors	Factor measurement
(Papaioannou et al., 2018)	Sustainability	120 (40 from each pilot site)	Attitude: the system is welcomed by the target users	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	interview		
(Pokric et al., 2015)	Education, Sustainability	23	Attitude: users respond positively to the proposed IeG system	Individual Engagement	Point of Engagement, Period of Sustained Engagement	questionnaire	Comprehensiveness: participants respond positively to the usage simplicity	questionnaire
(Poslad et al., 2015)	Sustainability, Transportaion	268 (Enschede), 112 (Leeds), 138 (Gothenburg)	Attitude: 50% participants report the system tasks are irrelavent and 30–50% report tasks are unfeasiblebehavior: 46% participants finished tasks, 34% got the reward (a pie)	Public Engagement	Period of Sustained Engagement, Long-term Engagement, Nonengagement	self-report, questionnaire, system log	Intrinsic incentive: participants report challenge and rewards have the potential to change behavior but this needs to be individualized and context based,Social incentive: social network features are rated best, however there is no proof that sharing information and experiences contribute to shifting travel behavior	survey
(Postolache et al., 2019)	Health Care/ Well being	8	Attitude: participants report general positive opinions about the system, motivation: participants consider that the system can increase patients' motivation for rehabilitation	Multi-user Engagement	Period of Sustained Engagement	Questionnaire; Expert Rating;		
(Pozzi & Sgardelis, 2016)	Crowd Sourcing	unknown due to technical trouble	Attention: large number of interaction records show passersby's attention is attracted behavior: low number of targeted behavior records show public is reluctant to engage (frequency)	Public Engagement	Point of Engagement, Period of Sustained Engagement, Nonengagement	analysis from interaction record		
(Tan & Varghese, 2016)	Health Care/ Well being	3000 in pilot, 156000 in national challenge	Behavior: increased and sustained target activities are reported in pre-post comparison (frequency)	Public Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	system log		
(Williams et al., 2019)	Skill training	504	Attitude: no statistical difference is reported in pre-post comparison of privacy concern. Behavior: significant difference is reported in pre-post comparison of certain privacy protection behaviors (frequency)	Individual Engagement	Period of Sustained Engagement, Long-term Engagement, Nonengagement	questionnaire, system log		
(Winnicka et al., 2019)	Smart Home/ Home Automation	3 families	motivation: participants report 8.33 out of 10 scale motivation to adopt the proposed system.	Multi-user Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	self-report	Social incentive (competition): participants agree that competition can enhance their motivation (average 8.33 of 10 scale)	questionnaire
(Rock Zou et al., 2015)	Education, Sustainability	13 in total	motivation: young children are reported to be motivated to follow green habits	Individual Engagement	Point of Engagement, Period of Sustained Engagement, Long-term Engagement	observation, interview		
(Kimura & Nakajima, 2019)	Sustainability, Crowd Sourcing	4		Multi-user Engagement	Nonengagement, Point of Engagement, Period of Sustained Engagement, Long-term Engagement		Intrinsic incentive: participants report that virtual rewards did not affect their motivation	focus group interview

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Reference Number	Domain	Participants	Cognitive-behavioral Engagement Outcome	Engagement Scale	Engagement Stage	Engagement Measurement	System Factors	Factor measurement
(Alexandre et al., 2019)	Health Care/ Well being	2	Behavior: The more users use the system, the higher the score each time (performance)	Multi-user Engagement	Period of Sustained Engagement, Long-term Engagement	system log		
(Radeta et al., 2019)	General Purpose, Entertainment	20	Attention: radio coverage perception increased to 35% of participants, remaining the same for 50%, while decreasing to 15% Attitude: 70% of participants were in favor of the game, pleasant and exciting scores are above averageMotivation: 75% of players reported the wish to frequently use IeG	Multi-user Engagement	Period of Sustained Engagement	interview, questionnaire	General usability: SUS score is 70.88/100	SUS
(Konstan-tinidis et al., 2014)	Health Care/ Well being	116 intervention, 116 control group	Motivation: 92.2% reported that the platform worth paying if it was ever marketed. Behavior: Adherence is 82% and the training efficacy of intervention group is statistically higher than control group.	Multi-user Engagement, Individual Engagement, Multi-user Engagement	Period of Sustained Engagement, Long-term Engagement	system log, questionnaire	General usability: SUS score is 76.36/100	SUS