MAINSTREAMING PREVENTION THROUGH DESIGN IN ENGINEERING EDUCATION

Shafienaz Ismail[1], Che Khairil Isam Che Ibrahim[1], Sheila Belayutham[1], Clara Man Cheung[2] and Che Maznah Mat Isa[1]

[1] *School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

[2] *Department of Mechanical, Aerospace and Civil Engineering (MACE), Engineering Building A, The University of Manchester, Oxford Road, M13 9PL, UK*

The integration of Prevention through Design (PtD) concept into the engineering education has evolved progressively in response to accreditation requirements. Despite the previous studies focusing on the integration of PtD principles into the curriculum, practical knowledge integration through effective teaching and learning mechanism remains elusive. The objective of this paper is to discuss the core elements of teaching and learning approach, as well as best practices in integrating the PtD concept into curricula. A systematic literature review was conducted based on 27 identified studies focusing on PtD education. The findings indicated that the current PtD educational approach incorporates five constructivist learning principles: content learning, outcomes learning environments, learning domains and pedagogical approaches. This study extends the PtD literature in the educational context, by providing insights into designing an effective curriculum for mainstreaming the PtD in engineering education.

Keywords: education; curriculum design; prevention design; constructivist learning

INTRODUCTION

Prevention through Design (PtD) in construction has been acknowledged by scholars and practitioners as one of the preventive efforts throughout the design phase to mitigate work related to risks and hazards, hence balancing occupational safety and health over the lifecycle of a project. The PtD concept has attracted growing research interest and practice in wide-ranging domains, including practicality and resources (Toole, 2017), technological advancements (e.g., (Din and Gibson, 2019)), sustainability (Stacey and Simpson, 2009), education (Behm *et al.,* 2014; Toole, 2017) and financial implications (ASCC, 2006).

Despite widespread adoption of PtD practice, practical implementation can be challenging. One of the notable challenges documented in the literature was the lack of knowledge and abilities among duty holders, notably designers, in addressing the OSH implications of their design in relation to the project lifecycle. One of the possible causes of concern was a lack of early PtD education in tertiary and continuing education. Research suggests that charting the curricula development toward PtD is

[1] shafi026@uitm.edu.my

Ismail, S, Che Ibrahim, C K I, Belayutham, S, Cheung, C M and Isa1, C M M (2022) Mainstreaming Prevention Through Design in Engineering Education *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 512-520.

an essential first step in enhancing graduates' competency towards safety and health (Hinze, 2000; Toole, 2017).

LITERATURE REVIEW

The PtD educational issues were initially highlighted in the early 2000s, with a focus on creating a commitment to preventative culture to ensure graduate designers had a solid foundation of the safe design prior to real-world work experience (e.g., Hinze, 2000; Mann, 2008).

Several studies (e.g. (Hinze, 2000; Popov *et al.,* 2013; Toole, 2017) have highlighted that one of the major barriers to incorporating the PtD into the curricula was the crowded curriculum among engineering programmes. Mann (2008) discovered that a lack of awareness on the occupational safety health (OSH) has contributed to designers' failure to create safer construction methodologies. Gambatese (2003) has emphasised that limited knowledge of OSH is one of the factors impeding the diffusion of PtD in the United States. Several other studies in different countries, for instance in Malaysia (Che Ibrahim *et al.,* 2021); in the UK (Stacey and Simpson, 2009); in Australia (ASCC, 2006) have acknowledged that the designers must improve their OSH knowledge and skills for PtD to be realised in their designs. It's worth highlighting that the possible reason for designers' lack of safety understanding is due to the lack of early safety education in tertiary education (Toole, 2017). Furthermore, it is thought that PtD practise among designers is conceived through training or courses are taken throughout their professional experience, rather than during their undergraduate education (Cortés et. al., 2012).

Although there have been examples of the current state of PtD education (e.g., Spain (Lopez *et al.,* 2015), the United States (Din and Gibson, 2019), and Malaysia (Che Ibrahim *et al.,* 2021)), as well as proposed educational approaches (e.g., Popov *et al.,* 2013; Wilbanks, 2015; Toole, 2017); little initiatives to investigate the integration of teaching and learning mechanisms into PtD practice. Thus, to fill the identified gap in the PtD education, this study explores the relation between PtD principles and teaching and learning approach based on the constructivist learning principles. This study is part of a wider study to understand the extent of PtD education in engineering accredited programmes. Gaining an insight on how PtD could be integrated into curricula could facilitate the academic transform of the present engineering curriculum into a practical transformational change in bridging the safety and health education gaps for engineering graduates.

METHOD

The overall review workflow was based on a systematic literature review, and it included three major phases: identification of articles, selection of targeted articles, and examination of the target articles. The scope of the review aimed to cover PtD related education literature in the construction domain, this study used a combination of diverse PtD terminologies and educational context. The search was based on 19 different key terms that were shown in either the title,

TITLE-ABS-KEY ("Prevention through Design" OR "Design for Safety" OR "Safety in Design" OR "Construction Design and Management" OR "Safety by Design" OR "Design for Construction Safety" OR "Design risk management" OR "Construction Hazards Prevention through Design" OR "Occupational Safety and Health in Construction Industry (Management)" OR "OSHCIM" OR "DfCWS" OR "DfCS" OR

"CHPtD" AND (“Construction") AND ("Education*" OR "curriculum" OR "teaching" OR "institution" OR "Pedagogy"))

The review exercise covered articles published from 2000 until the year 2021. The initial search found 46 related articles, including articles published in both journal articles and conference proceedings. Next, further screening was conducted to exclude 11 articles that were not related to construction (e.g., power plant, crime prevention) context, incomplete details, and duplication of conference articles (similar and greater depth of content was published as journal articles). The initial screening returned 35 articles from 17 different publications outlets.

The following inclusion criteria were used to select the articles to assess their relevance to the subject: (1) the article should focus (majority of the content) specifically related to PtD education context in the EAC domain; and (2) the article should emphasise at least on the perspectives, educational concepts, and approaches of PtD. Articles focusing on PtD but not on educational context were excluded from the sample, resulting in only nine relevant articles out of 35. To ensure that no significant publications on PtD education are overlooked, a snowballing technique was conducted. Finally, 27 relevant articles were finalised, with most of the articles (48%) coming from conferences, followed by journal and report articles (41% and 11%, respectively). In terms of geographical location, most of the authors (56 percent) were from the United States, followed by Australia and Malaysia with 11 percent each, and the remaining 33 percent were mostly from European countries (e.g., UK and Spain).

A qualitative thematic analysis was adopted to identify and synthesis the trend of PtD educational elements highlighted in the 27 articles. The inclusion of datasets from different sources over the past decades enabled the triangulation of elements for increased validity. Several initiatives have been proposed (ranging from academic capability, syllabus, innovative pedagogical approach, technology integration, etc) to instil safe design thinking and skills in graduates (Toole, 2017; Behm *et al.,* 2014).

FINDINGS

The Constructivist Learning Principles

The PtD educational elements were identified from the literature and were framed based on the five constructivist learning theory principles suggested by Terhart (2003) i.e., content, learning outcomes, learning environments, domain learning and pedagogical approaches. The consideration of the constructivist learning is appropriate due to the need of making sense of the knowledge, skills and experience related to PtD landscape during the learning process (Behm *et al.,* 2014; Toole, 2017). In framing the PtD engineering education, the constructivist didactics (CD) theory has offered must-have educational elements in integrating the PtD concepts and its principles into the curriculum structure.

The construction of CD in engineering education is mainly governed by two (2) main principles: (1) principle of learning which aims to create own learning of knowledge and experience and (2) principle of instructors which designs the strategies of learning of the learners based on the metacognitive of learning skills. These governing principles have constructed the curriculum into a practical pedagogy approach to achieving the intended learning outcomes. Another component that mechanises the learning is the didactics. Didactics is the approach of instruction from the instructor to the learners which stimulates and controls the learning through selected content, obligates a response from the learners, evaluates students' responses and provides reinforcement of correct responses or feedback for the learner based on the learning environments and facilities (Terhart, 2003).

Popov *et al. (*2013) further research how to integrate the PtD concept with constructivist learning principles by mapping the requirements set by accreditation bodies [e.g., Accreditation Board for Engineering and Technology (ABET); Engineering Accreditation Council (EAC) Joint Board Moderators (JBM);] (Che Ibrahim *et al.,* 2021; JBM, 2021). The requirements of mapping will align the PtD concept easily when the curriculum is compliant with the outcomes-based approach. The outcomes-based approach provides classical guidance on mapping the engineering content (e.g., health and safety risk management) within engineering teaching and learning approaches and demonstration of students' attributes to become competent safe thinking design engineers. The students' attributes for the curriculum will be designed based on the transferable skills (e.g., knowledge profiles; engineering analysis; engineering activities; engineering practice) based on the intended learning outcomes within the wide range of real scenarios in PtD practices.

The PtD Educational Elements

Many efforts have progressively grown in engaging the PtD practices in teaching and learning. Table 1 presents the summary of best practices of previous studies on PtD educational elements. It is worth noting, that there is a multifaceted relationship between the five (5) key elements of the constructivist didactics approach (content, learning outcome, learning environment, learning domain, and pedagogical approaches), the need to consider them dependently is crucial because each of these represents a key element to develop student's knowledge, attitude, and competency towards PtD practice when they work in the industry.

Content

The content is one of the significant mediums of didactics to craft the learning of the students (e.g., authentic materials; lesson plan consisting of learning activity and the learning outcomes). The literature indicated the dominant concept of PtD was incorporated into the existing course of design (i.e., steel design, concrete design, timber design) (Batson, 2013), safety and risk hazard management and risk assessment were mostly the chosen content to be small sub-topic incorporated in the course (Ghosh and Bhattacharjee, 2016; Maraqa, 2015; Popov *et al.,* 2013; Toole, 2017).

Occupational safety and health (OSHA) was introduced as a short course with a minimum of 10 hours of lectures inclusive of a day with visiting professional speaker sharing the notes and experience of safety practices at the site (López *et al.,* 2015; Mann, 2008). Several scholars (e.g., Behm *et al.,* 2014; Foley *et al.,* 2016; Lew and Lentz, 2009) have highlighted the exposure to construction techniques, legislation, regulation, policies, and ethics, are added as new topics in different existing subjects and new subject into the curriculum due to limited credit hours as strictly guided by the accreditation. However, many civil engineering programs are integrating sustainability into their curricula but focusing on environmental sustainability and economic sustainability (such as life cycle costing) but missing the third pillar of sustainability, which is social sustainability which is the core to the PtD principles (Toole, 2017).

Learning Outcomes

In terms of learning outcomes, most of the literature indicated that the intended skills acquired to perform in PtD practices are translated on how effective the learning environment will be created. The complex relationship between learning outcomes and the learning environment needs to be carefully designed for the students' exploration to attain knowledge is achieved through the capability of the course in guiding the students to develop knowledge and skills from their prior knowledge to more advanced learning. In particular, 'to address and to understand' the fundamental intended learning outcome of PtD practice is designed based on the sequential consideration of safety by designers in the phases of design, analysis, and safety consideration during the identification of hazards for workers and end-user (Bhattacharjee and Ghosh, 2011; Che Ibrahim *et al.,* 2020). Mostly the authors (Batson, 2013; Maraqa *et al.,* 2015), highlighted the chosen taxonomy used in developing the learning outcome is based on the development of lower order, intermediate and higher order of the taxonomy. It signifies the level of development of a student's cognitive domain (i.e., knowledge, comprehension, application, analysis, synthesis, and evaluation).

Learning Environments

Exposure of experiential learning space for PtD that creates student-cantered learning activities in meaningful learning experience related to the complexity of real-world PtD practices. PtD can serve as an engaging platform through classroom, workshop, and collaborative networking (Popov *et al.,* 2013; Toole, 2017). Bringing the real-world PtD practices into the classroom is favourable to the instructor so the students can get a real feel of commitment towards safety. Some of the engineering programmes invite speakers from the industry to share their knowledge and experiences with the students (Jia and Gilbert, 2017; Wilbanks, 2015). In terms of contextual design process evolves from the concept of contextual enquiry, where decisions are based on how users interact with the work environment, site visit exposure was introduced by Bhattacharjee and Ghosh, (2011); Toole (2017) and Che Ibrahim *et al. (*2021). An interactive environment of learning has been driven by the technology of digital transformation. The widespread technologies (i.e., building information modelling, big data, virtual reality, game-based, design simulation modelling) has been used to visualisation of OSH in the construction site environment (Che Ibrahim *et al.,* 2021; Din and Gibson, 2019).

Learning Domains

Expected competencies of knowledge, skills, and attitude to be acquired by learners in relation to PtD practices have been well addressed by (Che Ibrahim *et al.,* 2020) based on tacit, explicit, and implicit knowledge distributions based on the PtD practices. Many researchers (Batson, 2013; Behm *et al.,* 2014; Toole, 2017), are concerned about how the students instil the safety commitment when making a crucial decision that leads to providing facilities, and methods of construction to offer during the commencement of the project, the process that is relevant and economically viable to the client and user in managing the risk and hazard throughout the lifecycle of the project. As this is the most challenging effort, the students need to understand and be aware of the importance of having safe design thinking and commitment toward the workers and users. Furthermore, the central essence of skills is leadership skills as it will need to ensure the safety premises are kept and follow orders as per stipulated in the law and regulations. Furthermore his/her command is important as it will ensure the success of the project/construction in fulfilling and satisfying the need of PtD requirements.

Table 1: The best practices of PtD educational elements based on constructivist learning principles

Exemplary of Best Practices in Constructivist Didactics Learning Principles					
Content	Learning Outcomes	Learning Environments	Learning Domains	Pedagogical Approaches	Relevant authors (Examples)
Construction techniques; construction site safety; planning and operation	To address the construction technique in the safest practice	Classroom	Systematic thinking	Lectures; Training	Hinze, (2000); Gambatese, (2003); Lew and Lentz, (2009); Cortés *et al.* (2012)
Safety in design; safe design in lifecycle concepts; identifying hazards; PtD concept and its constructability	To understand the designing for safety issues and design decision making based on PtD concept and principles	Classroom; Workshop; Collaborative networking; interactive software; internship	creative thinking; communicate effectively; decision making; leadership	Lectures; Modules; Training	ASCC, (2006); Batson, (2013); Popov *et al.* (2013); Maraqa, (2015); Ghosh and Bhattacharjee, (2016); Toole, (2017)
Ethical role of the engineer	To understand the roles and responsibilities of duty holders within the framework of PtD	Classroom	Instilling commitment	Lectures; Training	Batson, (2013); Behm *et al.* (2014); Toole, (2017)
Construction techniques; identifying hazard	To understand the safety hazards recognition and designing solutions by substitution of tools and systems.	Classroom; computer/ paper-based game; internship; research project; site visit; workshop	Critical thinking	Lectures; Research; Training	Popov *et al.* (2013); Ghosh and Bhattacharjee, (2016); Din and Gibson, (2019)
Safety framework, legal and regulatory; public policy; legal duties	To understand the available laws and regulations based on the lifecycle of the project	classroom; workshop	critical thinking; forward thinking; leadership	Lectures; Training	Stacey and Simpson, (2009); Foley *et al.* (2016); Che Ibrahim, *et al.* (2021)
Concept of PtD; safety and risk hazard management; risk hazard assessment; lab safety	To understand the safety management and responsibility in managing risk	Classroom; internship; laboratory; multimedia; MOOC; site visit; seminar; websites	Critical thinking; leadership; systematic thinking;	Lectures; tutorials; visiting speaker	Wilbanks, (2015); Jia and Gilbert, (2017); Che Ibrahim *et al.* (2021);
Occupational Safety and Health (OSHA)	To understand the safety concept of hazard assessment at the site	Animated software; Classroom; competition; seminar; site visit	Competencies in risk prevention	Lectures; modules; visiting speaker	Mann, (2008); Popov *et al.* (2013); Lopez *et al.* (2015); Toole, (2017);

Pedagogical Approaches

Effective and innovative teaching delivery strategies are the key to drive experiential learning and crafting the mind of the learners through effective learning is notable.

The best practices have yet need to be improved as the instructor needs to be up to date with the current concept of PtD and some still use the traditional lecture-based educational modules that cover wider PtD dimensions.

The pedagogical approach that can be used in PtD teaching and learning proposed that using case studies as part of a risk prevention exercise could influence students' design thinking in terms of accident causality, prevention, and hierarchy of controls (Che Ibrahim *et al.,* 2022).

To nurture the low to high levels of skill attainment among the student, Popov *et al. (*2013) proposed three techniques (i.e., What if/Checklists, Failure Mode Effects Analysis and Preliminary Hazard Analysis and Risk Assessment) that could be embedded in the curriculum that aligned with outcomes-based learning. In contrast, suggested that technology-driven approaches such as computer-based and serious game is more effective to instil in the students' interest in acquiring the safe design thinking and instil the safety commitment during their lessons throughout their exposure to PtD practices in their programme.

CONCLUSIONS

The study adopted a systematic literature review approach to investigate the trend of how the PtD integrates into engineering education based on the constructivist didactics theory's learning guiding principles. In general, the current PtD educational approach is mainly focusing the identification and analysis of risk and hazard. The integration of wider fundamental and practical knowledge is needed to equip future engineering graduates with cognitive, practical, and affective attributes in the safety and health domain.

The finding generates insights into the five (5) key elements of PtD educational approach based on constructivist learning principles; (1) content, (2) learning outcome, (3) learning environment, (4) learning domain and (5) pedagogical approach. The first element, content is related to the exposures of breadth and the depth of PtD concept covers identification of risk and hazard, ethics, construction techniques and others through its curriculum to craft the meaningful learning of learners. The next element, the learning outcome is focused more on the aim of intended skills to acquire for each learning domain in terms of knowledge, skills, and experience to perform the PtD practices. The learning environment is described as exposure to an experiential learning space for PtD that creates learner centred-learning activities in meaningful learning experiences related to the complexity of real-world PtD practices. The fourth element, the learning domain covers the expected competencies of knowledge, skills, and attitude to be acquired by learners in relation to PtD practices. The last principle, the pedagogical approach deals with effective and innovative teaching delivery strategies of the instructor to deliver the PtD contents to the learners.

It is believed that these elements could drive the experiential learning PtD and creates the interest in the student's appreciation towards PtD practice. Furthermore, including these elements in existing curricula has the potential to increase the safety and health outcomes required by associated engineering professional bodies. Nevertheless, in acknowledging that the key elements are conceptual embedded, further research through quantitative and qualitative methodologies in different geographical contexts could be conducted to capture the PtD or safety and health best practices in the educational landscape to further improve the learning experience of future graduates in the tertiary education.

ACKNOWLEDGEMENT

This work described in this paper has been supported by the School of Civil Engineering, College of Engineering and funded by a GPK-Lestari Grant, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia [Ref No. 600-RMC/GPK 5/3 (082/2020)].

REFERENCES

Australian Safety and Compensation Council (ASCC) (2006) *Safe Design for Engineering Students: An Educational Resource for Undergraduate Engineering*, Available from: https://www.safeworkaustralia.gov.au/system/files/documents/1702/safedesignforengineeringstudents_introduction_2006_pdf.pdf [Accessed 24 June 2022].

Batson, R G (2013) Alternative approaches to incorporate design for safety into construction engineering curricula, *In*: *ASEE Annual Conference and Exposition*, 23-26 June, Atlanta, Georgia

Behm, M, Culvenor, J and Dixon, G (2014) Development of safe design thinking among engineering students, *Safety Science*, **63**, 1-7.

Bhattacharjee, S and Ghosh, S (2011) Safety improvement approaches in construction industry: A review, *In*: *Proceedings of the 47th ASC Annual International Conference*.

Che Ibrahim, C K I, Belayutham, S, Manu, P and Mahamadu, A M (2020) Key attributes of designers' competency for prevention through design (PtD) practices in construction: A review, *Engineering, Construction and Architectural Management*, 28(4).

Che Ibrahim, C K I, Belayutham, S and Mohammad, M Z (2021) *Prevention Through Design (PtD) Education for Future Civil Engineers in Malaysia: Current State, Challenges and Way Forward*, *Journal Civil Engineering Education*, **147**(1), 1-15.

Che Ibrahim, C K I, Manu, P, Belayutham, S, Mahamadu, A M and Antwi-Afari, M F (2022) *Design* for safety (DfS) practice in construction engineering and management research: A review of current trends and future directions, *Journal Building Engineering*, **52**, 104352.

Cortés, J M, Pellicer, E and Catalá, J (2012) Integration of occupational risk prevention courses in engineering degrees: Delphi study, *Journal of Professional Issues in Engineering Education and Practice*, **138**(1), 31-36.

Din, Z U and Gibson, G E (2019) Serious games for learning prevention through design concepts: An experimental study, *Safety Science*, **115**(January), 176-187.

Foley, B, Howard, P, Toft, Y and Hurd, M (2016) Increasing safe design practice within the engineering curriculum, *In*: *Proceedings of the 27th Australasian Association for Engineering Education Conference*, Coffs Harbour, Australia.

Gambatese, J A (2003) Safety emphasis in university engineering and construction programs Continuing Education, *Construction safety education and training.*

Ghosh, S and Bhattacharjee, S (2016) Can User Centred Design Methods Improve Construction Safety? *In*: *52nd ASC Annual International Conference Proceedings.*

Hinze, J (2000) The need for academia to address construction site safety through design, *In*: *Proceedings of Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World*, **278**, 1189-1195.

Jia, A Y and Gilbert, D (2017) The content and pedagogy of project safety management in the construction management curriculum: Does design matter, *In*: *Joint CIB W099 and TG59 International Safety, Health and People in Construction*, 585-592.

JBM (2021) *Guidelines for Developing Degree Programmes (AHEP3) (Version 2)*, *Institution* of Civil Engineers.

Lew, J and Lentz, T J (2009) Strategic education initiatives to implement prevention through design (PtD) in construction, *In*: *International Proceedings of the 45th Annual Conference*, Gainesville, Florida, Associated School of Construction, University of Florida.

López-Arquillos, A, Rubio-Romero, J C and Martinez-Aires, M D (2015) Prevention through Design (PtD) The importance of the concept in engineering and architecture university courses, *Safety Science*, 73, 8-14.

Maraqa, M A, Sweedan, A M I S and Zaneldin, E (2015) Inclusion of construction health and safety in engineering programs in the MENA region: Assessment and potential enhancement, *In*: M Abdulwahed, M Hasna and J Froyd (Eds) *Advances in Engineering Education in the Middle East and North Africa*, Cham: Springer, 261-299.

Mann, J A (2008) Rapporteur's report education issues in prevention through design, *Journal of Safety Research*, **39**(2), 165-170.

Stacey, N and Simpson, K (2009) *Integrating Risk Concepts into Undergraduate Engineering Courses, RR702: Research Report*, Norwich: HSE.

Popov, G, Blunt, L A, McGlothlin, J, Young-Corbett, D, Zey, J N and Heckel, P (2013) Education integrating PtD into undergraduate curricula, *Professional Safety*, *58*(03), 44-49.

Terhart, E (2003) Constructivism and teaching: A new paradigm in general didactics? *Journal of Curriculum Studies*, **35**(1), 25-44.

Toole, T M (2017) Adding prevention through design to civil engineering educational programs, *Journal of Professional Issues in Engineering Education and Practice*, **143**(4), 1-15.

Wilbanks, D W (2015) Prevention through design: A curriculum model to facilitate hazard analysis and risk assessment, *Professional Safety*, 60(04), 46-51.