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Difficulties, Preconceptions and Misconceptions that Hinder Learning Lean Construction and Ways to Overcome these Obstacles: A Literature Review

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Abstract

Challenges, preconceived notions, and misunderstandings that obstruct the learning of lean construction requires identification and the design of corrective instructional strategies. Therefore, the inquiry arises as to whether the conceptual transformations brought about by the recommended instructional strategies can be assessed. The purposes of this paper are to identify difficulties, preconceptions and misconceptions that hinder learning lean construction, to forward effective instructional interventions to overcome the problems from scholarly literature in engineering education, and to give ways to measure conceptual changes attained by the suggested instructional interventions. Identification of difficulties, preconceptions and misconceptions in learning lean construction are made, and suggestions on effective solutions from scholarly engineering education literature forwarded. Assessment strategies of conceptual change brought about by the suggested instructional interventions are also forwarded. Pertinent literature on teaching lean and difficulties in teaching lean construction are reviewed from lean research. Difficulties, preconceptions, misconceptions, conceptual change, concept inventories and assessment of learning are reviewed from engineering education research. Difficulties, preconceptions, and misconceptions in lean construction are identified from lean research papers, and instructional interventions are forwarded from engineering education research. The idea is to bring in information from engineering education research to solve instructional problems in teaching lean construction. Difficulties, preconceptions and misconceptions that hinder understanding of lean construction concepts are identified from lean scholarly literature. How these problems hinder learning lean construction are pointed out, and effective instructional interventions suggested with ways to assess conceptual changes attained by suggested instructional interventions from scholarly engineering education literature. The best way to assess conceptual change is by using concept inventories but because lean construction is an emerging field internationally, concept inventories are not yet developed for it. Concept inventories are developed for mature fields and few concept inventories are developed internationally in such fields and subjects as physics, biology, chemistry, computer programming, statics, etc. Learning objectives-based rubric and assessment sheet are the only available ways to assess conceptual change in lean construction, which has got some limitations. Effective lean learning facilitates lean implementation and practice. Learning lean construction will be more effective and faster if educators can identify problems that hinder learning so that effort is directed towards overcoming the issues. Findings help better understanding of teaching methods to use in case learners have difficulties, preconceptions and misconceptions. Information from this research can be used in future research to develop concept inventories in lean construction, which is the recommended tool to cure misconceptions.

Key Words: Difficult concepts, preconceptions, misconceptions, conceptual change, concept inventories, learning lean construction.

1. Introduction

The formation of conceptual knowledge is a key element in the development of competence and expertise in engineering (Streveler et al, 2015). There have been several efforts to formulate conceptual knowledge on lean construction (Bashir et al., 2010; Sarhan and Fox, 2013). Despite the large volume of publications, it seems issues such as difficulty in understanding concepts, lack of specific technical skills, lack of training, lack of holistic approach in implementation, appear to be some of the barriers to lean practice (Bashir et al, 2010). Moradi and Sormunen (2023) carried out systematic literature review to summarize and integrate fragmented researches using 230 selected studies and tried to develop a comprehensive understanding of barriers, enablers, and implications for adopting and implementing lean construction. Their findings suggest that the lack of awareness and understanding of lean construction, resistance to change, and a lack of support and commitment from top management are the top three barriers. They concluded these barriers can be overcome using the identified enablers, the top three of which are developing lean culture, application of lean principles, tools and techniques, and top management support and commitment. Lack of awareness and understanding of lean construction can be overcome through lean education and training. Application of lean principles, tools and techniques can be facilitated by learning and training. It may prove easier to learn lean construction if content educators could systematically identify difficulties, preconceptions and misconceptions that hinder learning lean so that curriculum development and pedagogical design will be directed towards overcoming the road blocks of adaptation and implementation.

An individual's conceptual understanding of a topic is the collection of his or her concepts, beliefs, and mental models (Streveler et al, 2015). Chi (2008) contends that as people build conceptual knowledge, knowledge is organized hierarchically into categories. Conceptual change is the process of altering one's conceptual understanding, beliefs, and mental models. What an individual learns is at least partially controlled by what he/she already knows, i.e., by the preconceptions, misconceptions and the correct conceptions a learner already has.

This paper presents some of the difficulties, preconceptions and misconceptions that hinder learning lean construction concepts and recommends instructional interventions to correct erroneous conceptions to improve effectiveness of teaching and learning lean construction. The paper also gives ways to assess conceptual change attained by instructional interventions.

2. Definitions

Lean Construction: Lean construction is a project management philosophy that adapts the principles of *lean manufacturing* to the design and construction process. The main goal is to *maximize value* for the client while *minimizing waste* in all forms. This is achieved through a collaborative system that focuses on creating a predictable and continuous workflow. Unlike traditional construction, which often operates in silos with each team (e.g., designers, engineers, contractors) focused on optimizing their own phase, lean construction emphasizes *overall optimization*, *collaboration* and *respect for people*.

Difficulties: The first roadblock to conceptual understanding are difficulties in the concepts. Perkins (2009) advocates that curriculum designers identify concepts that are difficult for students and work on those concepts to make sure students understand them. One of Perkins' classifications of difficulty is abstract vs concrete, in which lean concepts such as flow, value, waste, variability and work in progress fit the abstract classification (Perkins, 2009). Other sources of difficulty listed by Perkins include conditionality versus universality classification of difficulty (Perkins, 2009). Example of conditionality is the dependence of effectiveness of application of lean principles on the context of the company or project due to the many factors affecting effectiveness of the application. Waste can further be broken down to physical waste (trash), which is easy to see; however, process waste (waiting, over-processing, unused talent) is often "invisible" to the untrained eye.

Preconceptions: The second obstacle to conceptual understanding are preconceptions or prior knowledge barriers. These are the "naïve" beliefs learners bring with them based on years of traditional project management experience. These are often the hardest to unlearn. Preconceptions are problematic when a paradigm shift occurs from one explanatory framework to another such as the earth revolving around the sun as opposed to the sun revolving around the earth. One lean construction example is preconceptions of ideas learned in undergraduate construction management and civil engineering courses, which were correct conceptions according to the traditional construction management paradigm but are not congruent with lean construction paradigm such as push planning in traditional construction management versus pull planning (look ahead planning) in lean construction. The second example is siloed optimization and success in traditional construction management as opposed to overall project optimization and success in lean. The third example is quest to protect oneself from claims transferring risks to the other party in contracts, which results in adversarial relationships. The lean requirement of radical transparency and trust using relational contracting or integrated project delivery feels dangerous or unrealistic.

Misconceptions: The third road block to learning and understanding lean are misconceptions. These are "false facts" or "flawed mental models" that students come with to learn lean. Students come to learn not as blank sheets, but with different levels of knowledge and concepts about the topic they learn (knowledge base). When this knowledge base is framed differently from the correct scientific conception, the knowledge base obstructs students learning of the concepts. These prior incorrect conceptions are called misconceptions. One of the causes of misconceptions, according to Chi (2008) is mis-placement of a concept in a category or level in a hierarchy where it does not belong. Instructional interventions should be targeted at three grain sizes depending on where the misconceptions occurred: individual beliefs, mental models and categories. A category mistake to inappropriate lateral or ontological category causes robust misconceptions (i.e., misconceptions that are difficult to cure). Taber (2012) classifies misconceptions according to how they impede learning into: null and substantive impediments. Null impediment refers to misconceptions that impede learning because students lack information to construct the scientifically accepted conception. Substantive impediment refers to faulty concept models that students have constructed.

Reception and understanding of a learner are at least partially controlled by what he/she already knows, i.e., by the misconceptions,

preconceptions and the correct conceptions a learner already has. Conceptual change is the process of altering one's conceptual understanding, beliefs, and mental models. Preconceptions and misconceptions are known to resist conceptual change, which require targeted effort and method to overcome them.

Concept inventories: are specialized, research-based assessment tools designed to measure a student's deep conceptual understanding of core concepts and to reveal common student ***misconceptions.*** Unlike typical exams, which might test for a wide range of knowledge, concept inventories focus on a small set of core concepts. Few concept inventories are developed, and for well-established fields.

3. Alternative Theories of Conceptual Change

There are three prominent theories of conceptual change, which are built on opposing descriptions of conceptual understanding as either (1) a hierarchical categorization of knowledge (Chi's group), (2) a weak grouping of experiences and perceptions (diSessa's group), or (3) a form of social behaviour. One of the main issues in the psychology literature on conceptual knowledge is whether the students' knowledge is organized in a coherent structure or whether it is fragmented. In the early work on acquisition of conceptual knowledge related to force and motion, McCloskey (1996) postulated that students' conceptual knowledge, even when it is incorrect, is "theory-like" in that it is well organized and applied consistently.

Other researchers advocate an opposing view, namely that students' knowledge is not coherent or theory-like. Minstrell and colleagues (e.g., Hunt and Minstrell, 1994; Minstrell et al., 1992; Minstrell and Stimpson, 1996) have identified relatively independent explanatory facts, "facets," that students use to explain phenomena, some of which are correct and others of which are incorrect. diSessa (1988) advocates a similar view that students' knowledge is fragmented and "in pieces" and that it is not applied consistently in different contexts.

These competing models describing the organizational nature of students' naïve conceptual knowledge have different implications for informing the selection of instructional methods that would be most effective in helping students build correct and coherent bodies of conceptual knowledge. The implications of the two models for instruction have, however, received only limited attention in the literature. diSessa et al. (2004) discuss this topic briefly, noting that if students' knowledge is coherent then instructional approaches that focus on comparison of a few models, including the correct one, may be an appropriate approach. The fragmented knowledge model would suggest that instructional methods must allow for substantial individual differences among students, so focusing on only a few competing models may not be the best instructional approach.

There have been several efforts to formulate conceptual knowledge on lean construction (Bashir et al., 2010; Sarhan and Fox, 2013). Despite the large volume of publications in lean construction, it seems issues such as difficulty in understanding concepts, lack of specific technical skills, lack of training, lack of a holistic approach in implementation, appear to be some of the barriers to lean practice (Bashir et al, 2010). There are few papers on teaching/learning lean, none of which treat difficulties, preconceptions and misconceptions in lean construction based on scholarly work in engineering education. It may prove easier to learn lean construction if content educators could systematically identify difficulties, preconceptions and misconceptions that hinder learning so that curriculum development and

pedagogical design will be directed towards overcoming the roadblocks.

4. How to assess (Measure) conceptual Changes?

Assessment is essential to gather evidence that will demonstrate whether the learners have learned what we want them to learn. Assessment is the process of reasoning from evidence. To design assessments of student learning that will provide useful evidence requires that we coordinate and align three key components:

a. ***cognition***-which refers to a model of the thinking and learning of students within the subject domain.

b. ***observations***-the tasks or activities that students engage in that provide evidence of learning, and

c. ***interpretations***-the process or methods for making sense of the evidence as shown in the assessment triangle in Fig.1.

Assessments are effective and useful only to the degree that these three components are in alignment. If we design tasks without clearly thinking about if and how those tasks will require students to demonstrate the targeted knowledge and skills, we may end up with data that doesn't address our goals. Alternatively, if we design tasks without thinking about how we will analyse the performance, we may end up with data that don't allow us to detect students' strengths or weaknesses.

The cognition corner, the starting point of assessment development, requires the researcher to explicitly commit to formal or informal theories about how people learn in the target discipline. Thus, the cognition corner identifies the chosen learning theory as the foundation for developing any assessment.

Learning objectives-based rubric and assessment sheets may be used for assessment, but their limitation is that they are not effective in detecting misconceptions and changes (cures) in misconceptions. Concept inventories are often used as measures of conceptual change, and more indirectly, as measures of pedagogical practices that may promote conceptual change (Streveler et. al 2015). Concept inventories are multiple choice questions specifically on the misconceptions. One of the choices will be correct, one choice will be the misconception as a distractor, and two other choices. There are few concept inventories developed by educational researchers because their development and validation take a lot of time and resources. The first one developed is force and motion concept inventory in physics. Streveler et al. (2011) used the process shown in Fig. 2 based on the assessment triangle to develop concept inventories for Thermal and Transport Science (Thermal and Transport Science Concept Inventories – TTCI).

In the cognition corner, students' important misconceptions are identified using a Delphi study (Fig. 3) and validated with current learning theory. Fig. 4 gives the process used to develop and validate the Thermal and Transport Science Concept Inventories (TTCI) question items.

Concept inventory tests are given to students before they learn topics to identify misconceptions. Concept inventory tests are then administered after misconceived topics are taught (using the appropriate instructional methods) to see the change in the concepts.

5. Difficulties in learning lean construction

Pellicer et. al (2014) say that lean construction is an emerging field, and as a result, different theoretical interpretations, complex terms, multiple approaches, and abstract concepts make learning lean construction challenging

either in an academic environment for students or while training for professional development. When describing ideas and concepts in an emerging field like in lean, the development of a shared language should be the first step (Stone, 2012). The first most likely cause of difficulty in learning lean is that there is not yet a consensus on the definition of the terms like 'lean' or 'lean construction', 'value', 'waste', 'flow' and 'continuous improvement' (Stone, 2012; Ogunbiyi et al, 2011; Salvatierra-Garrido et al, 2012; Viana et al, 2012; Lahy and Found, 2015). This is supported by Perkins' work (2009), who reports that terms and language can hinder learning. A second cause of difficulty is a lack of spatial-temporal cognition skills, such as an ability to visualize facilities and their evolving processes as they get constructed (Shen and Zhu, 2017). Spatial complexity, which obstructs understanding of construction management in general, is related to the space arrangements of various components of a facility under construction, as well as the cognitive effort of construction professionals to understand and mentally visualize such arrangements (Shen and Zhu, 2017). The notion of temporal complexity arises in the construction industry, from uncertainties associated with the execution and sequence of activities on a construction project and uncertainties with arrival/availability of information, dependent work tasks, human resources, space, material, equipment, external conditions, and funds (Shen and Zhu, 2017; Hamzeh, 2009; Koskela, 2000). Another case of temporal complexity occurs when several predecessor activities must be completed with different probabilities of completion for a successor activity to begin (Hamzeh, 2009). Difficulties in construction also arise due to the dynamic coupling of the spatial and temporal elements, i.e., as the construction progresses on different parts of the facility with time, making the outcome an emergent process (Shen and Zhu, 2017; Goldratt and Cox, 2004). An example of such an emergent complex process is the total duration of activities due to the dynamic coupling of dependence and variation in a construction work flow. This emergent process is misattributed as a direct causal outcome, that causes a misconception. The third source of difficulty associated with learning lean is that lean construction concepts such as 'value', 'flow', 'pull', 'waste' and 'continuous improvement' are abstract concepts, making it difficult for students and novice professionals to grasp and apply (Pellicer et. al, 2014; Perkins, 2009). A fourth source of difficulty for learners exposed to lean is that the key lean construction concepts such as flow, value, pull, waste and continuous improvement are threshold concepts (TCs). Though threshold concepts are beneficial, serving as conceptual gateways (Meyers and Land, 2003) that can inform a transformative understanding of lean principles for use in construction, they are often difficult to understand. Benefits of threshold concepts (TCs) also include the fact that they are generative in that they open up many new ideas to learners and can progress the learner into expert-like knowledge understanding and use. They are also integrative in that they help see previously hidden interrelatedness among concepts. The fifth learner difficulty relates to the fact that lean principles and methods are not based on physical or social laws, but rather were developed gradually over many years at Toyota empirically and hence are heuristic rather than rationally based (Koskela, 1997; Gao and Low, 2014; Ohno, 1988). The sixth and final potential area presented to explain learning difficulty, relates to individual preconceptions and misconceptions. Preconceptions are correct conceptions according to a traditional (often outdated) construction management paradigm, but they are not in line with the lean construction (new) paradigm, thus hindering ones' ability to learn lean construction concepts. Alternatively, misconceptions result from assigning items to a

wrong framing or taxonomy (Chi, 2008). An example includes the total construction duration or cost of a project, which in current practice are taken to be direct result of duration or cost of individual work tasks, respectively. The reality is that total construction duration or cost indirectly results from or emerges from individual task durations or costs and interactions between the trades. Goldratt and Cox (2004) showed that the outcome in such a case depends on combined effect of dependence and variation. A small change in one of the factors can amplify and result in a butterfly effect (Jacobson and Wilensky, 2006). Principle of emergence in a complex system needs to be applied. Therefore, flow is a process that falls under emergent process category as opposed to direct causation (Vosiniadou, 2008; Chi, 2008). The following section aims to elaborate up on and provide clarity specifically around the issues and impacts of learner preconceptions and misconceptions on his/her conceptual understanding in lean construction.

6. Preconceptions and misconceptions in lean construction

The use of concepts (or conceptualizations) function as organizers when learners are presented with new instructional content (Streveler et al, 2015). Experts are known to organize their knowledge around key concepts or 'big ideas' (Streveler et al, 2015). Helping students acquire conceptual knowledge can help them acquire more expert-like knowledge structures. An important theme in the literature on conceptual change focuses on why some misconceptions are difficult to correct in learners. Research postulates that as students try to make sense of new concepts, they do so by forming analogies familiar to their experiences (Streveler et al, 2015). Chi (2005) has developed an alternative argument for why some misconceptions are more robust (i.e., difficult to cure) in learners than others. She posits that there are two classes of phenomena: direct and emergent. Direct phenomena are those in which causal connections are readily observable and in which the concept components involved have clear function (e.g. delay in arrival of material by a supplier delays work activity that uses the material). Alternatively, in emergent processes, the observed phenomena are not directly caused by the underlying physical processes, but rather emerge indirectly from them (e.g. total duration of series and convergent activities in a network schedule is not the sum of durations of individual activities along a path but emerges from the individual activities considering precedence dependence between activities and variation in duration of each activity (probability of completion of an activity within the activity duration). As such, Chi notes that emergent concepts are particularly difficult to understand, and may misattribute the concept to direct causation (Chi, 2005). Helping students recognize the emergent nature and resulting patterns from system interactions may assist them in learning these difficult concepts (Slotta and Chi, 2006; Howell, 1999; Jacobson and Wilensky, 2006), by halting the development of early misconceptions.

6.1 Preconceptions

As discussed prior, preconceptions present a different form of learning obstacle from misconceptions. Preconceptions are often ideas learned in undergraduate construction management and civil engineering courses, which were correct conceptions according to the traditional construction management paradigm but are not congruent with lean construction paradigm. Forbes and Ahmed (2011) listed differences between traditional construction management and lean construction. The authors believe that the correct terminology to use for the traditional conceptions acting as barriers to understanding lean concepts is

preconceptions. Graduate students taking lean construction course and professional engineers taking lean construction trainings come with this prior knowledge of traditional construction management principles (preconceptions) that need to be corrected to help understanding of lean concepts. Table 1 gives preconceptions held by engineers in graduate school or in professional practice that hinder understanding of lean construction concepts.

6.2 Misconceptions

Misconceptions are "false facts" or “flawed mental models” or any aspect of an individual’s conceptual understanding, perhaps even one type of pre-conception, that resists conceptual change and contributes to incorrect, naïve or unproductive conceptual understanding (Streveler et al, 2015). Toyota Corporation developed lean manufacturing concepts (Gao and Low, 2014; Ohno, 1988). As such, they have crystalized lean thinking into the following five guidelines: specify value, identify value streams and remove waste, make the process flow, let customer order pull production, and continuous process improvement to perfection (Forbes and Ahmed, 2011). Common misconceptions that learners often acquire after a surface-level introduction to lean are:

- Many believe lean construction is simply the Toyota Production System (TPS) copy-pasted into construction. This leads to the rejection of concepts that don't seem to fit the "temporary" and "unique" nature of construction sites.
- Lean is misconceived as a tool to cut cost and lay off people. A common fear is that lean is a corporate tool for layoffs. In reality, lean focuses on maximizing value and eliminating waste, not necessarily reducing headcount.
- Learners often think lean is just a set of "toolboxes" (5S, Last Planner System, BIM). They fail to realize it is a management philosophy and a cultural shift.
- Learners think that lean makes work faster/easier. While lean removes waste, it often fills that saved time with more value-added work or continuous improvement tasks. This can make the workday feel more intense rather than easier.

Key concepts in Toyota’s guidelines as well as Koskela’s Transformation-Flow-Value (TFV) theory of lean production management (Gao and Low, 2014; Koskela, 2000) are ***flow, value, pull, waste, work in progress, variability and continuous improvement.*** In spite of the wide use of lean principles and practice in manufacturing and across industries (Forbes and Ahmed, 2011; Stone, 2012), there are persistent misconceptions regarding these key concepts that hinder understanding them.

One of the misconceptions within the lean concepts relates to *flow.* In particular, individuals associate flow with fluid flow in a pipe or flow in a channel (Hamzeh, 2009). The other misconception regarding flow is the category under which people place it as they organize the concept in their mind. Work process flow and work in progress are emergent processes. Treating total duration in construction work flow as a direct effect of the duration of individual activities is a misconception that hinders understanding. Total duration is emergent from dependence between activities and variation in duration of each activity.

Misconceptions regarding *value* is that people think about it in monetary terms. Another issue with the concept of value, is that it falls under neither *entity* (with attributes: can be contained, has weight, and occupies space), *process* (with attribute: occurs over time) nor

*mental state (*a person's emotional, psychological, and cognitive well-being) in Chi's classification. As an example, value is often defined in terms of function and quality, which fall under different categories (function is close to process and quality to mental state), whereas cost doesn't fall under any of the three categories. Chi (2008) recommends that people add new categories laterally. A new category may be added, or a more comprehensive categorization may be picked from the plethora of categorizations available in philosophy literature. An example of a more comprehensive categorization is Aristotelian realism, which gives high-level categories as: substance, quantity, quality, relation, place, date, posture, state, action, passion (Stanford, 2019). Hoffman and Rosenkrantz (1994) lay out a tree-form system of categories, with *entity* the *summum genus*, subdivided into *abstract* and *concrete*, each of which is further subdivided: *abstract* into - property, relation and proposition; *concrete* into - event, time, place, substance (material object, spirit), limit, collection, privation, trope. Cost falls under abstract and is a monetary property or measure. This categorization helps better to categorize ***value*** and ***waste*** (waste has value in it).

Regarding concept of ***pull***, it belongs to a process. The misconception associated with ***pull*** is that we understand it as exerting force on something to move it towards ourselves. Pull is a production system that is activated into production by actual customer demand (when order is received) (Hamzeh, 2009).

The misconception with ***waste*** is that we think of it in objective terms (material and time wastes) whereas the subjective or intangible aspects such as not meeting the client's and/or user's needs, desires and expectations, are as important, if not more important.

Misconception about ***continuous improvement*** is that people do not consider it as a structured and disciplined approach. It involves performance measurement, comparing actual values with target and stretch values, using the feedback for improvement and repeating the cycle (Plan-Do-Check-Adjust (PDCA) cycles).

7. Effective teaching methods

Design of effective teaching methods to overcome difficulties, preconceptions and misconceptions are suggested by researchers. Shen and Zhu (2017) recommend context-rich case-based and problem-based teaching method to teach students complex phenomena. While real engineering problems are complex and dynamic, most problems discussed in classrooms are static, well-structured, where parameters of the problems are specified. Skills learnt through static class room problems are difficult to transfer to practice. Skills developed through context rich cases, problems and semester project transfer to practice easily because these are near transfer.

Instruction suggested to overcome preconceptions and misconceptions are (Vosniadou, 2008):

- moderate use of dissonance strategies like cognitive conflict (showing conflict and contrast between correct and erroneous conceptions)
- the use of constructive strategies like analogies
- model-based reasoning by learner construction of qualitative and quantitative models using technology-based tools
- discussion including peer instruction, collaborative reflection, and some computer-supported collaborative learning
- convergence-divergence type of reasoning including hypothesis-experiment-instruction.

In model-based reasoning, analogical, imagistic

and simulative modeling are argued to be productive means of conceptual change. Games, simulations and interactive team semester projects are used in teaching lean (Tsao et al, 2013, Pellicer et al, 2014, Nofera et al, 2015), which are in line with model-based teaching.

There is no research on effective pedagogies for misconceptions in lean construction. The closest topic researched is pedagogy to treat misconceptions in statics. Krause et al (2010) and Kelly et al (2010) ranked the following five pedagogies from most effective to least effective in remedying different misconceptions in statics: (1) team discussions with hands-on activities and concept sketching; (2) team discussions with contextualized concept mini-lectures and activities; (3) team discussions, contextualized concept lectures and activities, plus pre-/post-topic assessments and daily reflections; (4) lecture with some discussions; and (5) lecture only with no team discussions or activities.

Menekse et al (2013) evaluated the effectiveness and applicability of the Differentiated Overt Learning Activities (DOLA) framework, which classifies learning activities as interactive, constructive, or active, for engineering classes, which can be applied to misconceptions in lean construction. They tested the Interactive, Constructive, Active, Passive (ICAP) hypothesis that student learning is more effective in interactive than constructive activities, which are more effective than active activities, which are in turn more effective than passive activities (traditional lecture). Interactive activities are the most effective. Peer instruction and semester project learning environment are interactive types.

Dollar and Steif (2008) developed an object-centered online learning system for statics course from statics concept inventory and statics concepts for computer-based instruction, and they found that it is effective. Using figures makes concepts concrete for engineering students. A figure speaks more than a thousand words. In many universities giving lean construction courses, games and simulations are found effective in aiding students understanding of the abstract concepts of value, flow and waste (Tsao et al, 2013, Pellicer et al, 2014, Nofera et al, 2015). Games and simulations help students understand abstract concepts because the pictures and objects in the games and simulation activities make things concrete for them. They also understand the emergent outcomes of the different actions and decisions they take at different points in the processes of the games and simulations, which will repair some of the misconceptions. Student course evaluations show that these games and simulations are effective in helping students understand the concepts (Pellicer et al, 2014, Nofera et al, 2015). Chi (2012) recommended simulations for emergent processes, which is the case for the interdependent construction activities and decisions demonstrated by the Parade of Trades®. The last five years has witnessed replacement of physical games by virtual simulations (Ouma et.al., 2024, Desmarais and Alves, 2024, Tommelein, 2024, Stevens and Poshdar, 2024). Lean education is also moving from teaching specific tools (like 5S) to a "holistic philosophy" approach (Forcael, et. al, 2025). Forcael, et. al (2025) paper argues that by embedding lean into the broader curriculum (BIM, sustainability, and ethics), educators can prevent the misconception that lean is a peripheral "toolbox" rather than a core management philosophy. Further, Moradi and Sormunen (2023) lean teaching has moved from simply explaining "what lean is" to addressing the deep-seated cognitive (abstract concepts, unlearning preconceptions and invisible wastes such as process wastes) and structural/cultural barriers (lack of immediate results, far transfer of knowledge and skills from a 2-hour class room simulation to a 30 billion Birr high rise

building project, and resistance to standardization as a threat to creativity or academic freedom) that prevent lean adoption. The shift has been driven by a "digital-first" mindset (accelerated by the corona pandemic) and a closer integration with modern project management technology (BIM, AI, IoT, virtual reality and augmented reality).

In sum, it is very important that the learning environments selected and designed are aligned with the way assessment is made, and assessment is in turn aligned with the sources of learning difficulty, including persistent pre-conceptions and misconceptions. The learning environment selected will help overcome the difficulties (abstract concepts, emerging field, emergent processes, preconceptions and misconceptions) and aid students' learning. Suitable observation (data collection on student performance in learning activities) and interpretation of the results need to be made accordingly.

8. Conclusions and recommendations

Difficulties that hinder ones learning of lean construction include issues associated with spatial and temporal complexity, the lack of consensus on definitions of core lean terms, the abstract nature of the core lean terms and concepts, and learner preconceptions and misconceptions around key concepts. Instructional interventions are suggested to aid in overcoming the identified issues, including assessment strategies of conceptual change. Developments in virtual games (simulations) and lean-BIM integration are encouraging developments, that help overcome some of these lean instructional road blocks. Such interventions are hoped to improve instructional effectiveness for the learners, and adoption/implementation of lean into the industry at large.

There are no PhD level courses in construction engineering and management at many universities on lean construction, and students take courses from other areas. Taking courses from other areas has the advantage of saving resources but its disadvantage is that transfer of knowledge is difficult because it is a far transfer, i.e., students expend a lot of time and effort to apply principles from other areas to their own research. Giving such a course (s) and remedying the difficulty, preconceptions and misconception issues contributes to advancing lean construction, and to higher research and publication productivity in lean construction.

Table 1. *Preconceptions that hinder learning lean construction vs correct conceptions*

Preconceptions that act as barriers to understanding lean construction	**Correct lean construction conceptions**
Push planning	Pull planning
Rewarding individual crew performance	Rewarding all disciplines involved in completing major sections of a project
Local optimization by individual participating parties (contractor, designer or subcontractor)	Optimization at overall project level
Projects treated as controllable and relatively predictable based on critical path analysis	Lean uses CPM schedule milestones and focuses on short-term planning and control such as using Last Planner System, focuses on flexibility and learning to cope with uncertainty and unplanned events
Management by control is used and the focus is to track cost and time	Lean focuses on adding value
Isolated and disintegrated management by designers, constructors and subcontractors	Involves management philosophy of integrated and collaborative management by all stakeholders for mutual benefit

Preconceptions that act as barriers to understanding lean construction	**Correct lean construction conceptions**
Variability stems from external causes (leading to failure to actively manage variability)	Large majority of plan failures were with in contractor's control
Parties try to protect themselves in contracts from claims that make construction contracts "adversarial"	Lean requirement is radical transparency and trust using relational contracts or integrated type of delivery with a win-win outcome

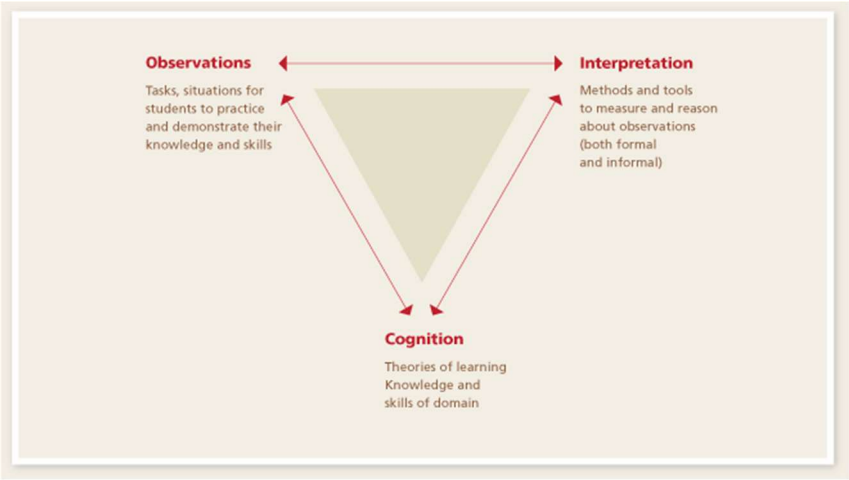


Fig. 1. Assessment Triangle

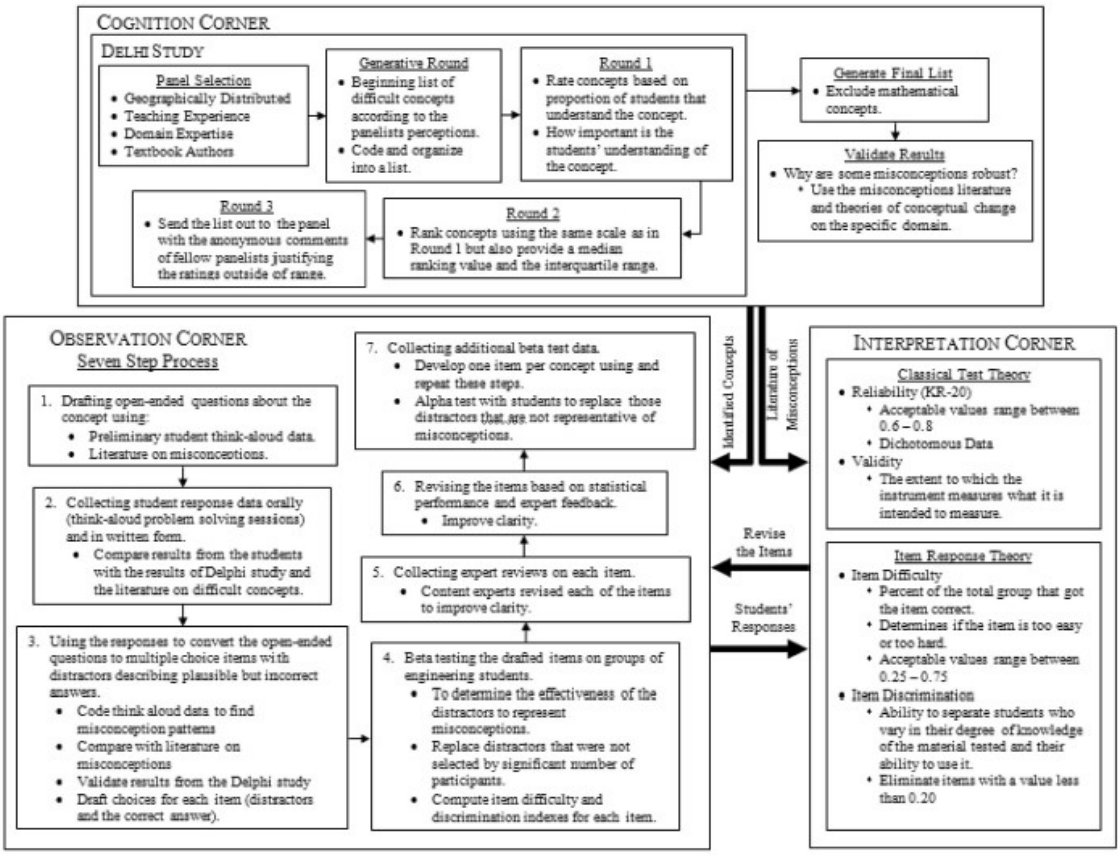


Fig. 2 Process used to develop the TTCI (Streveler et. al, 2011)

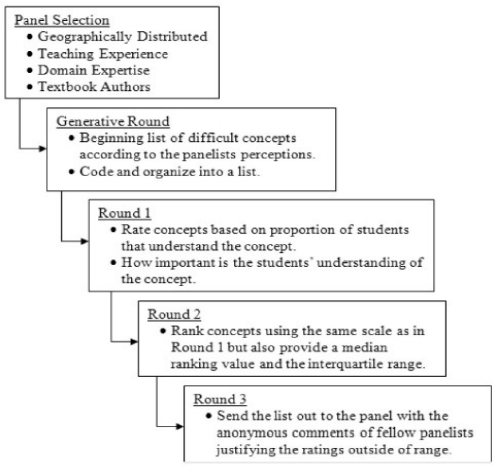


Fig. 3 Graphical representation of the Delphi study applied to the TTCI (Streveler et. al, 2011)

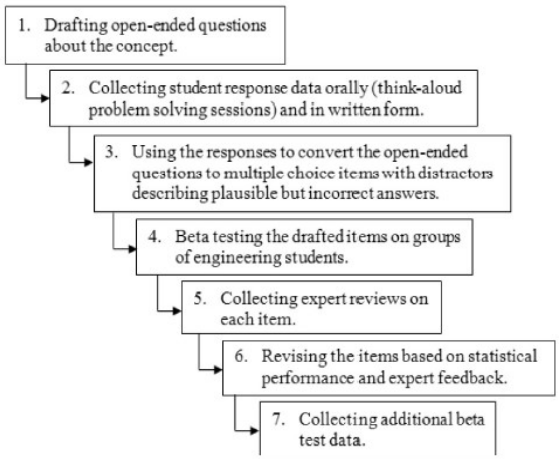


Fig. 4 Graphical representation of the process used to develop TTCI question items (Streveler et. al, 2011)

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