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Mistakeproofing! It's in the Cards: A Serious Game

Iris D. Tommelein[1]

Abstract

Question: Can a serious game instill enthusiasm and pique interest in the practice of mistakeproofing by teaching its principles and related Lean thinking?

Purpose: The purpose of this paper is (1) introduce a new game, adding to the suite of serious games for Lean Construction education and training, (2) to describe the origin of this new game that is designed to teach the principles of mistakeproofing based on learning from examples, and (3) to provide an overview of the game.

Research Design/Method: Inspired by hundreds of mistakeproofing examples, the author created a new card sorting game. She prototyped the game using a deck of poker-sized playing cards and also created an online version. Since 2020, the game has been played numerous times, facilitated by the author or other people. Lessons learned from industry and academic players' plus/delta feedback continue to drive improvements.

Findings: The game is now used in educational and professional settings around the world. Many players have an 'aha' moment as they begin to recognize mistakeproofing applications in construction and other contexts, and when they assess the qualities of these applications by sorting examples according to the principles explained in the game. Informal feedback suggests that the game has pedagogical value and is fun to play.

Limitations: A formal study is yet to be conducted to measure what and how much players learn about mistakeproofing.

Implications: The game is evolving as players develop their own example cards, based on observed or newly inspired applications. For now, we can only speculate what and how much players are learning about mistakeproofing by playing the game.

Value for practitioners: Mistakeproofing is an everyday practice, especially for—but not limited to—people who are implementing Lean thinking. It will benefit everyone to know the six principles and learn how to do their own mistakeproofing.

Keywords: Mistakeproofing, poka yoke, principles, online education, serious games, Lean Construction.

Paper type: Technical paper

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Introduction

The card game presented in this paper and called "Mistakeproofing! It's in the Cards" (further referred to as *Mistakeproofing!*) stemmed from my desire as a teacher to increase awareness and understanding of the Lean practice called mistakeproofing, its principles, and related Lean thinking. This topic fills a 1.5-hour lecture in *CE268A Lean Construction Concepts and Methods*, one of two graduate-level Lean Construction courses I teach at the University of California, Berkeley.

Mistakeproofing! is a so-called serious game, a term coined by Abt (1970). "A serious game or applied game is a game designed for a primary purpose other than pure entertainment. […] The idea shares aspects with simulation generally, including flight simulation and medical simulation, but explicitly emphasizes the added pedagogical value of fun and competition." (Wikipedia 2024b)

This paper describes the origin of this card game that is designed to teach the principles of mistakeproofing based on learning from examples. The background section on recent developments of Lean Construction games is followed by a section providing definitions and citing key source documents pertaining to mistakeproofing. The section thereafter gives an overview of the *Mistakeproofing!* card game's ontology and how the game is played. The contribution to knowledge of this paper is to let readers know that this game exists and can be obtained from the author. The game itself is a contribution to the suite of serious games used for Lean Construction education and training (Bhatnagar et al. 2023).

Recent Developments of Lean Construction Games

Launch of Administering & Playing Lean Simulations On-Line (APLSO)

The world shut down in March 2020 due to the COVID-19 pandemic. This forced many to shelter in-place and learn how to fully function in an online, more virtual world. Educators, students, and practitioners alike, especially those who had been using hands-on simulation games to teach and learn Lean Construction, were left scrambling because face-to-face meetings—akin to "going to the gemba" and so important in the process of learning to see with one's own eyes—could no longer take place.

After an email with a cry for help from Annett Schöttle on March 21, 2020 (Schöttle 2020), sent from Germany and addressed to the author and 21 other people involved in the International Group for Lean Construction (IGLC), several enthusiastic email replies followed. Among others, Zofia Rybkowski located in Texas, USA, immediately shared her experience and followed up with providing specifics about her "Maroon and White" game and the Architectural Programming simulation she had played at the 27th Annual Conference of the International Group for Lean Construction (IGLC27) in Dublin, Ireland (Solhjou Khah et al. 2019, Rybkowski 2020). Later that day, she sent an email inviting the community with the lead-in "If anyone would like to meet as a community and try out playing some Lean Games On-Line using Zoom, and then share your plus/delta feedback with the group" and she provided a link to an online poll. In a subsequent email she added "so we can start scheduling a first run study session together as soon as possible. I am envisioning we might start a regular Zoom meeting where individuals could test out their

games on one another and receive instant feedback before they take the games to their students and/or clients." Thus, she launched the group Administering & Playing Lean Simulations On-Line (APLSO), a group for educators, students, and others to test and develop ideas for new (online) games (Rybkowski et al. 2021). Interest spread by word of mouth, and by the end of 2023, 174 individuals from 21 countries had requested to join APLSO, keenly interested in using lean simulation games as both an experimental and pedagogical tool. Attendance at APLSO has grown and now includes even more people from all over the world. The group is still meeting monthly for a 1.5-hour long video conference, using the Zoom platform. Necessity is the mother of invention!

Mistakeproofing! It's in the Cards

I have been intrigued by the practice of mistakeproofing for a long time and I feel it is a fundamental concept in Lean Construction—and in Lean Thinking in general—that has not received as much attention as it deserves. Some papers on this topic have been published in the Proceedings of the Annual Conference of the IGLC (e.g., dos Santos and Powell 1999); however, there are not many. About 20 years ago I began to record examples specific to design and construction (Tommelein 2008 includes some of these examples), and I have gathered hundreds since. A lot can be learned from this collection (e.g., Tommelein and Demirkesen 2018, Tommelein and Yiu 2022).

Back in 2019, with Zofia and others, I attended the IGLC27 in Dublin. My paper (Tommelein 2019) received the second place Best IGLC Paper Award. As a bonus, I was invited to present it at the very end of the conference. This is a tough time slot because it is hard to keep everyone interested until the very end. Rather than lecture, I therefore made the presentation interactive by explaining six mistakeproofing principles and asking the audience to look at examples, one at a time, to tell me what principle it exemplified. Many enjoyed the exercise, and I did too. So came about the game "*Mistakeproofing!* It's in the Cards."

In March 2020, Annett and Zofia's emails made me think how I could incorporate my examples into an online game to teach mistakeproofing practices. Based on a physical prototype I already had made, I figured out that Google slides could serve as the platform for a relatively easy implementation of the sorting game I had in mind, allowing remotely located players to move their virtual cards to the desired position on a virtual card table.

As an aside, let me also mention that with the COVID-19 shutdown and everyone's desperate need to keep teaching, I received several inquiries about whether the "Parade of Trades" simulation (P2SL, no date) existed in an online version. In fact, a long time ago we developed a computer-based discrete-event simulation (Tommelein et al. 1998, 1999) and a stand-alone computer-based version of the Parade of Trades (Choo and Tommelein 1999). Both programs still work! However, other implementations exist of course (e.g., I have seen a more elaborate, interactive, and graphically pleasing version in Microsoft Excel that colleagues created in 2020).

Greg Howell Game Room at the IGLC28 Conference

The game "*Mistakeproofing!* It's in the Cards" was played for the first time on July 9, 2020, in a virtual game room during the 28th Annual Conference of the International Group for Lean Construction (IGLC28). This was a first in several regards. IGLC28 was the

first IGLC conference held entirely on line—due to COVID-19 it was the only option we had, short of postponing that year's conference to a later date—and the game was part of our first Game Room.

It so happened that Emmanuel Daniel and I were serving as the technical chairs for this 2020 Conference (Tommelein and Daniel 2020). All the Conference planning and preparation efforts that we had started 2 years earlier had been progressing well until the moment the world shut down. The Conference's overall chair backed out from his commitment to host an in-person conference in Cusco, Peru. Emmanuel and I bravely offered to host the Conference online as we were close to wrapping up the peer-review process of papers and we felt that postponing our group's get-together to discuss these papers should not wait another year. Brave we were!

This was also the first time an IGLC conference included a session with games. Sadly, on June 15, 2020, we lost one of our great minds of Lean Construction, Greg Howell (LCJ 2020). Fondly remembering Greg for so many teachings, including learning first-hand from him how to use games (such as the aforementioned Parade of Trades) to let students experience concepts, I named the session at the Conference the Greg Howell Lean Games Room. The session, all online, had seven parallel game rooms, including one for the *Mistakeproofing!* game described here.

By now, a games session has become a regular part of the IGLC's annual conference program and continues to be hosted by Zofia. At each of the subsequent IGLC conferences I have had the pleasure of facilitating the *Mistakeproofing!* game with groups of about 20 and up to 45 participants from around the world. I have also used the game in lunch-and-learn sessions with industry participants. Former participants in the *Mistakeproofing!* game are now using the card deck in their classrooms and industry project settings not only in the US, but also in Canada, Brazil, Columbia, Denmark, Germany, France, Israel, India, Australia, and possibly other countries as well.

Having described how the *Mistakeproofing!* game came to be, the following section offers some background on mistakeproofing based on the literature.

Literature on Mistakeproofing

Definitions

Mistakeproofing or poka yoke in Japanese "is the use of any automatic device or method that either makes it impossible for an error to occur or makes the error immediately obvious once it has occurred (ASQ 2024)." The ultimate objective of mistakeproofing is to reduce the occurrence of — and at best to eliminate altogether — defects in construction products and processes.

Merriam-Webster (2024) defines mistake as (1) a wrong judgment: misunderstanding, and (2) a wrong action or statement proceeding from faulty judgment, inadequate knowledge, or inattention. This definition implies that one can discern right from wrong, that is, a reference norm or standard must exist to allow for this determination.

The terms mistake and error are often used interchangeably even though they differ slightly in meaning. It is common to refer to mistakeproofing as errorproofing. However, mistake and defect have notably distinct meanings. A mistake occurs at a point in time

whereas a defect is a follow-on consequence of that occurrence. If you are fast in catching the mistake, you can take corrective action before the mistake turns into a defect. Understanding this notion of "mistake first, defect later" is important and foundational to the framework used in the *Mistakeproofing!* game. It is a realization made clear in Shigeo Shingo's book (1986) where he argues that "zero defects is absolutely possible," notwithstanding the fact that to err is human.

The name of the card game includes the idiomatic expression "It's in the cards," which conveys that something is likely to happen. Yes, mistakes (errors) are likely to happen and, yes, mistakeproofing can and should happen too. While it is impossible to guarantee that no mistake will ever occur, we can reduce the likelihood of a mistake occurring or detect the mistake and alleviate its impact.

Spelling

How to spell mistakeproofing (in a single word), mistake proofing (two words), or mistake-proofing (with a hyphen)? English dictionaries such as Merriam-Webster.com (op. cit.) are mute about the question. People spell it in all sorts of ways. For the same usage in a single document, some may even spell it differently — mistakenly! As the English language is ambiguous in this regard (think of words such as lovemaking and moonlighting vs. decision making or is it decision-making?), for this game, the standard is to spell it using a single word. Having a standard makes it possible to spell-check and maintain consistency.

Origins of Mistakeproofing

The origins of mistakeproofing are impossible to trace. To err is human, but people are inventive, and mistakeproofing practices have therefore been around for a long time. Adages that refer to mistakeproofing practices such as "measure twice, cut once" are age-old. For practices in more recent history, the literature points to Sakichi Toyoda's invention in the late 1800s of a mechanism for an automatic loom to stop working as soon as its thread breaks, thus signaling the "flaw" or "error" and preventing that defective fabric would continue to be produced (Toyota 2024).

A more recent practical example is the use, e.g., in the Richmond Shipyards in California during WWII, of shadowboards to make it easy to put tools in their correct place and to readily see if any are missing. Figure 1 illustrates a shadowboard used in a maker space at UC Berkeley today. This board is used not only to help keep the maker space orderly, but also to teach students the correct English names of various tools.

Another practical example is the invention of the gang nail connector plate in the early 1950s "used in building construction specifically for the joining of timber truss joints of roof, floor trusses and prefabricated wall panels" (Figures 2 and 3) (Wikipedia 2024a). It is much easier and faster to join pieces of lumber using a gang nail plate, than to hammer in one nail at a time possibly at the wrong angle, bending the nail, or hitting one's hand.

While mistakeproofing practices are widely used around the world, there probably is no company quite like Toyota that has as deeply embedded a mistakeproofing mind set in its people at all levels of the organization and throughout its production system. Mistakeproofing offers a means to tackle undesirable variability and create production system stability that is essential to allow for continuous improvement.

Figure 1. Shadowboard (© Iris D. Tommelein, 2024)

Figure 2. Galvanized nail plate

(By Abcd2011 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=112901327 CC-BY-SA-4.0 visited 14 June 2024)

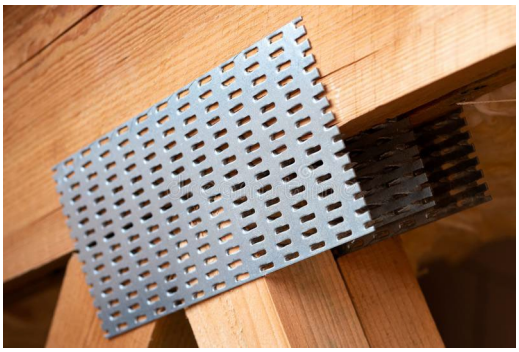

Figure 3. Detailed truss with galvanized nail plate (https://commons.wikimedia.org/wiki/File:Detail-truss-galvanized-nail-plates-166332487.jpg CC-BY-SA-4.0 visited 14 June 2024)

In the late 1970s and early 1980s papers written in English began to be published by Japanese authors describing the Toyota Production Systems, some mentioning mistakeproofing (e.g., Suzaki 1985, Nakajo and Kume 1985). The latter introduced a rudimentary framework on which the *Mistakeproofing!* game is built. Shimbun (1988) published a catalog of 240 illustrated examples to inspire readers — including the author of this paper — to use various practices that achieve mistakeproofing.

This notwithstanding, Shigeo Shingo is widely credited for the advancement of poka yoke approaches in the context of built-in quality systems. It is said that he saw the need for mistakeproofing during a factory visit in the 1950s, where he noted that workers inadvertently left out parts from an assembly. Shingo was a long-time consultant to Toyota in Japan and disseminated many Lean principles and methods in the English-language

literature when he moved to the US in the 1980s (Roser 2014a). His book "Zero quality control: Source inspection and the poka-yoke system" is a must-read for anyone interested in mistakeproofing (Shingo 1986).

Mistakeproofing Games

The *Mistakeproofing!* game presented here is certainly not the first serious game to teach mistakeproofing. I had the opportunity and pleasure to host John Grout for a P2SL workshop on mistakeproofing in 2018 and he used a Lego™ police car in a hands-on exercise. He also published numerous examples (Grout 2007). Christoph Roser (2014b) uses Kinder™ eggs to illustrate designs created for ease of assembly. An online search led to the Velaction (2020) exercise that highlights the benefits of creating jigs as a means to direct people to use the correct pieces and put them in the correct place when making an assembly.

The game presented here differs from those mentioned in that it involves classifying cards with examples according to mistakeproofing principles. I selected these examples from the database of examples I collected over the years, and I designed the cards. The *Mistakeproofing!* framework was derived from prior depictions in Nakajo and Kume (1985) and Godfrey et al. (2005). The creation of this serious game is my original work.

The game design was informed by the realization that (1) people do not recognize many mistake-prone and hazardous situations they encounter on a daily basis, (2) people feel they cannot speak up about them when they encounter them, and (3) people don't know what countermeasures may already exist or what approaches may be used to address them (e.g., based on principles of mistakeproofing) in their work or in the industry at large.

Pötters et al. (2018) studied the importance of mistakeproofing (poka yoke) in relation to other quality methods used on the shop floor of a serial production system, namely (1) 5S, (2) Kanban, and (3) Standard Work Sheets, using three KPIs: (1) rework, (2) lead time, and (3) adherence to delivery dates. For as much as I agree that mistakeproofing must be taught in relation to other Lean methods, in my view setting out to choose "the" right method is somewhat of a misconception. Methods are interdependent and complement each other to support the system. They must be used synergistically and according to the application context. Implementation of one method does not have to be prioritized over other methods, because in the end they may all be able to work together. I quite favor Paul Akers' "2 Second Lean" (Akers 2014) mindset with the notion that any time is a good time to stop and fix what bugs you (e.g., things you forget, or what you feel is not done right or can be done better), and fixing does not necessarily have to take a whole lot of time. Resources may prevent you from using all applicable methods at once, but you can be judicious in choosing what to implement next and proceed stepwise, in kata fashion (Rother 2009).

The following sections describe the specifics of the *Mistakeproofing!* game, first the game ontology and second the game's progression.

Ontology of the *Mistakeproofing!* Game

Lucko and Senior's (2022) ontology for (virtual) serious games suggested that eleven elements be described. These are enumerated next for the *Mistakeproofing!* game (albeit in an order different from theirs), highlighted in **bold**, and expanded on further in this paper.

1. The **rules** of "*Mistakeproofing!* It's in the Cards" are defined and illustrated in the sections that follow. Facilitation of the game is explained in Tommelein (2023).
2. The **board** can be as simple as a table, any other flat surface, or a virtual "page" on which cards will be laid out.
3. The **props** are the game cards with principles and examples. Examples cards on a virtual page are shown in Figure 4.

Figure 4. Excerpt of the online game "*Mistakeproofing!* It's in the Cards" implemented using Google Slides

4. The randomness in this game stems from any **ambiguity**[2] players encounter when interpreting an example shown on a game card according to their degree of understanding of the principles, their forcefulness in trying to convince others that their assessment is correct, and team dynamics.
5. The game is typically played in small teams of 4-6 **players** so that their individual learning can be enriched by hearing any divergence in perspectives that may be expressed in discussion.
6. Each player will receive and own several cards. For each card they own, individually, a player must decide on the best location to place that card on the game board. They don't have to wait for a **turn** to put their card down.
7. Players can **move** to place their card on the board at any time while other players are doing the same with their own cards.

[2] Element 4 in Lucko and Senior's (2022) ontology is "uncertainty" but in the case of the *Mistakeproofing!* game "ambiguity" is a better descriptor.

8. Playing with a team is better than playing the game alone, because then players can **communicate** their thoughts to others about the suitability of places on the game board and they can help each other understand the concepts and resolve ambiguity.
9. Players organized in teams can **collaborate** and amplify another player's arguments for putting a card in one place or another on the board. Disagreements are typical, so there will likely be discussion to reach agreement — if agreement can be reached — on where each card fits. Further group discussion across multiple teams offers players the opportunity to better come to grips with the mistakeproofing concept and to understand how to apply it.
10. When all players on a team have put their cards on the board and they have obtained reasonable agreement that the card placements are correct, they can share their findings and rationale with other teams. This concludes a **round** of the game.
11. The game does not use any means for scoring results. Completion of a round is **recorded** and marks the start of a new round, if applicable. New concepts can be introduced and decks with additional examples handed out. When all rounds have been completed, the game ends with an overall debrief on lessons learned and a plus/delta.

Mistakeproofing! Game Progression

The *Mistakeproofing!* game must start with a discussion to reach shared understanding among player on the definition of the concept "mistake" and what synonyms or related terms they have for it (an error, slip, mishap, etc.). In particular, the distinction "mistake first, defect later" must be conveyed and accepted as a premise.

In Round 1, an example card is presented and explained. Each example card has an image and a brief description in the title (see the two example cards shown in Figure 4). In addition, it presents a concern and a countermeasure. The concern describes something that might go wrong, i.e., a mistake that might be made. The countermeasure describes a mistakeproofing practice either to reduce the likelihood of the mistake being made or to alleviate the impact of the mistake after it has been made.

Then players are asked to decide whether the countermeasure is effective either before the mistake can be made or after the mistake has been made. Accordingly, they position the card along the work operation timeline (see each of the two cards shown in Figure 4, which are positioned correctly relative to the possible occurrence of the mistake of concern). Subsequently, additional examples cards are dealt and players decide where to position them. In a group debrief, players decide on the best position for each card.

In Round 2, the Work Operation Framework is introduced together with its six mistakeproofing principles. Figure 5 depicts this framework with four rectangular boxes positioned along the previously mentioned timeline marked by the possible occurrence of a mistake, namely (1) [Tasks Risks], (2) [Human Functions Required: Memory, Perception, and Motion], (3) [Abnormalities], and (4) [Effects].

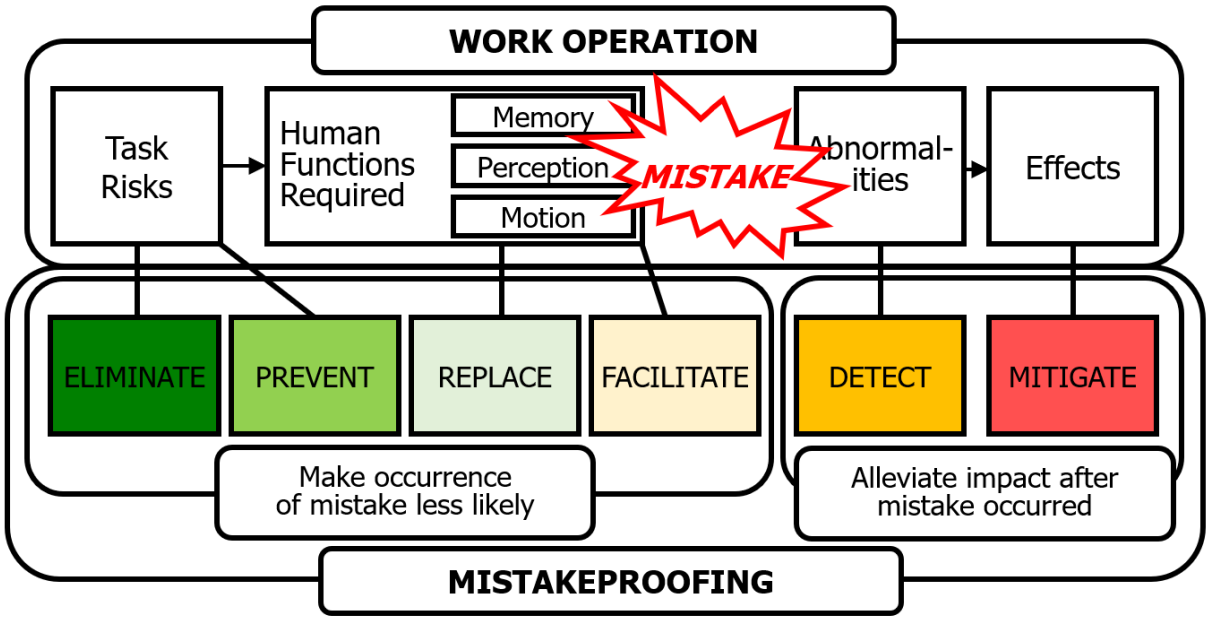

Figure 5. Work Operation Framework showing applicability of six mistakeproofing principles to work operations (adapted from Figure 3.1 in Nakajo and Kume 1985 and Figure 1 in Godfrey et al. 2005).

The first two boxes along the timeline come before the mistake.

[Tasks Risks] refers to the design of the work to be done (the design of the product or service to be provided, with a specification of means and methods, and an expectation of the operator's process capability) before any one person gets involved in doing that work.

[Human Functions Required: Memory, Perception, and Motion] refers to a person now doing the work, requiring human cognitive- and dexterity skills combined with the use of sensory feedback.

The last two boxes along the timeline come after the mistake.

[Abnormalities] means that one or several deviations from the standard has been noted, where the standard defines what is considered to be "good."

[Effects] describes the final outcome that will ultimately resulting in a defect (as per Shingo's terminology).

Figure 5 lays out the six mistakeproofing principles based on when they apply in the course of executing work (steps in an operation). They fall into two categories. In category I are Elimination, Prevention, Replacement, and Facilitation, namely the four principles to make the occurrence of a mistake less likely. In category II are Detection and Mitigation, namely the two principles to alleviate the impact once a mistake has occurred.

Tommelein and Demirkesen (2018 pp. 7-9) defined these six mistakeproofing principles as follows:

1. "Elimination (paraphrased as "don't do it anymore") is to remove the possibility of a mistake occurring in a task of a process by redesigning the product or process so that the task (or associated product part) is no longer necessary.
2. Prevention ("make sure it can never be done wrong") is to design and engineer the product or process so that it is impossible to make a mistake at all.

3. Replacement ("use something better") is to substitute one process with a more reliable process to improve consistency.
4. Facilitation ("catch people's attention, help them make fewer mistakes") is to use various means (e.g., sensory input) to make tasks easier to perform.
5. Detection ("notice what is going wrong and stop it") is to identify a mistake promptly so that a person can quickly correct it and thereby avoid that the mistake would turn into a defect (Shingo 1986).
6. Mitigation ("don't let the situation get too bad") is to minimize the effect of a mistake. Grout (2003) calls this 'designing benign failures.'"

In Round 3, now given this framework and set of principles, players are asked to decide which principle is realized by the countermeasure on each card. They must position each card already on the board to line up with the principle it illustrates (Figure 6).

In Round 4, additional examples cards are dealt and players decide how to categorize them by principle and position them accordingly. As in the previous round, in a group debrief, players decide on the best position for each card.

Figure 6. 2020 Prototype of *Mistakeproofing!* game cards.

To conclude this "learning to see" exercise by sorting example cards, participants can also be invited to make their own cards with examples. The ultimate objective of the *Mistakeproofing!* game is to give participants a framework to think about the possibility and timing of the occurrence of mistakes, and to encourage them to apply the principles of mistakeproofing in their own day-to-day work.

Conclusions

"*Mistakeproofing!* It's in the Cards" is a novel, serious game to teach mistakeproofing principles and practices by illustrating the application of those principles

using a deck of cards with various examples. By sorting cards with examples, participants discover what they can do to reduce the likelihood that mistakes will happen and potentially result in defects.

When played in teams, the game helps to develop a common vocabulary and shared understanding. The newly gained vocabulary of mistakeproofing principles and the examples depicted on the cards will enable players to express concern about mistake-prone situations. By fostering peer-to-peer discussion during the game about work operations design with an eye to reducing the likelihood of mistakes occurring, a psychologically safe environment can be created for team members to speak up about what they see and to call out concerns for potential mistakes.

A key benefit of gamifying learning, as is done in *Mistakeproofing!*, is that playing a game is enjoyable and memorable for everyone involved. The *Mistakeproofing!* game helps people keep quality and safety on their mind and builds team spirit.

The *Mistakeproofing!* game kit comprising 25 poker-sized cards and moderator instructions can be purchased for a modest fee from the author. It is a teaching tool that will serve Lean Construction educators and practitioners well in their education, training, and other continuous improvement efforts.

Acknowledgments

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