ANNALISA WEIGEL: So let's start with--

HUGH MCMANUS: I'm Hugh McManus, the co-creator of the lean enterprise value simulation. I'm going to talk a little bit about teaching lean thinking principles through hands on learning with particular reference to what we do in the Lean Academy. Credited here are Eric Rebentisch Tisch, my co-creator in the lean enterprise value simulation. And Earl and Alexis, who were key in integrating the lean enterprise value simulation, part of it, into the Lean Academy.

The reason we use simulation-based education for this is that teaching lean is is a difficult challenge. A great deal of that is because it's experience-based and it depends on a context, the context of existing industrial and engineering processes that are not familiar to students. So we really need to give them something to think about and work with before a lot of these ideas start to make real sense to them. So we use simulation-based education to increase comprehension. To allow them to put the ideas together in a more holistic, way not just bits and pieces of technical knowledge, but how does it all work together? And of course learning through experience, getting a tactile feel for the material.

Final thing for an intensive event like the Lean Academy is also just to get the energy rubbed off. To give them something to do. To get their blood pressure up a little bit. To keep them awake and excited and involved in the class. The simulation is built around attempting to build LEGO airplanes that are actually relatively poorly designed LEGO airplanes, if the criteria for a LEGO airplane is that it's relatively easy to put together and it stays together once you put it there. This is not a very good airplane.

And it's built in a very unlean way. It's built in a legacy system which has an unbalanced production system with bottlenecks and other problems. A long supply chain. A long and uncoordinated supply chain. The LEGOs actually come from someplace else. They have to be transported to the table where the airplanes are built. And there's a lot of paperwork and communications issues in both getting the plane built. And then at the end of each round, doing the accounting necessary to figure out whether you actually made money or not from the airplane.

The system used in the Lean Academy is moderately simple. We have four manufacturing plants that build tails, fuselages, wings, and final assembly to deliver an airplane to the customer. We have a supplier quality representative who interacts with a supply chain consisting of a single dedicated supplier, but in a different place. At a table where the suppliers sit. So there's a flow of information between these people. And hopefully that creates a flow of parts, of subassemblies in parts, that result in some value being delivered in aircraft being delivered to the customer.

The simulation it's not just a matter of building LEGO airplanes. It's actually a fairly rigidly defined simulation that has a number of features. For one thing, each student what they're allowed to do is represented visually like this. Each student is set is told, take these pieces and build that assembly. This both defines what they need to do visually so it's fairly easy to understand and it's changeable. Very important. This is a rather difficult assembly to put together. If the students wish to change it, they can in an organized way.

The processes that they do are also constrained by hourglasses. It's not a dexterity contest. It's not a race. It's a process. And this process is at many steps constrained by the pace of some hourglasses in particular, the assembly operations. Depending on the part count, hourglasses with different times are used to represent the actual factory operations that are happening. That are simulated by the simulation. It's not just a matter of the student's dexterity. And so this becomes a constraint that the students have to work with and design solutions around.

There's a fairly long paperwork chain and it's fairly clumsy. It's not that hard to learn but it turns out it's not that easy to use. Standard paper order form here. You could think of that even as a web form in the modern economy. But you're just saying, I want this many of this part, handing it off to your supplier quality representative, who then hands it to the supplier who has to fill it. And then they have to fill out essentially an invoice sheet that they send back to you. That means that every transaction with LEGOs involves two pieces of paper and 1, 2, 3, 4 steps just to get your parts to build. Not a very good system but not atypical of the real world.

And finally there's an accounting system for Lean Academy. It's a cash flow system that tracks all the costs involved. A fixed costs. How much does it cost to keep your plants open? The variable cost. How much do those parts cost? What does it cost to do various things? And you can figure out whether you're making money or not. Often you're not. And if you don't get out enough airplanes, you don't make any money. Or if you do things in a wasteful way, if you waste parts, you won't make any money.

ANNALISA WEIGEL: All right everybody. Let's check in. I'd like to find out how many planes each table built. Let's start here. One plane.

AUDIENCE: One.

ANNALISA WEIGEL: One plane? Two planes. One plane. All right. Who's making money?

AUDIENCE: No one.

ANNALISA WEIGEL: Let me ask a question. Is anybody's manufacturing operations making money yet? No. OK. Tell me how much money the supplier is making whose profitable?

AUDIENCE: 14.

ANNALISA WEIGEL: 14. OK. So you're barely profitable. That's better than being negative. All right. So the supplier might be doing well in that enterprise, but it might be at the expense of the manufacturing portion. So this is something that you're going to think about as you go through your simulation.

HUGH MCMANUS: So in the Lean Academy we dedicate one day to the simulation, about 2/3 of the teaching time in that day. There's some lectures interspersed. It happens in 12 minute active rounds-- there's 12 minutes of frenzy. Followed by on-- preceded by in many cases, time for reflection, planning, financial analysis, and so forth. And these are separated up into basically learning how to do the simulation, getting past the learning curve. Understanding how lean process improvements can be used to take a legacy state and make it lean and make it work better.

And then a final round where the manufacturing suppliers and also a not simulated, but conceptual engineering process, is used to achieve enterprise lean by redesigning the airplane, tuning the supply chain to a really high state, and seeing what you can do in an almost ideal state.

ANNALISA WEIGEL: This is a common tool around the industry to go and look at other facilities and benchmark yourselves not only with respect to companies that do the same thing as you do, but also to benchmark yourself against companies that do other things but have similar processes to you. So there's a lot to learn by going and walking around and seeing this. And from what I took away from the tables, I think we've got two different build-to philosophies going on. So you'll notice there are two kinds of build-to packages going on. Just take a look at that and see what cause somebody else to think differently than what you did.

I also wanted you guys to notice this table here. Because I saw you guys. You flipped your bins upside down when you are ready for a new ones. That was your signals?

AUDIENCE: This wasn't, we don't want anymore. This is, we do.

ANNALISA WEIGEL: And that's you do want more. So I saw that and I thought that was an interesting practice. Anybody else have a practice that worked well for them that might not come out when you're doing your table tours and just looking at the static display?

AUDIENCE: The clock [INAUDIBLE].

AUDIENCE: We used one timer for all four of us.

AUDIENCE: Oh no.

[INTERPOSING VOICES]

AUDIENCE: No. Then we're all synchronized. We're all--

[INTERPOSING VOICES]

ANNALISA WEIGEL: So there's a best practice that you might consider adopting. Did we have a comment from this team here?

AUDIENCE: Yeah. We color coded our bins and then color coded our standard order sheets so that she would be able to identify more quickly.

ANNALISA WEIGEL: OK, so did everybody hear that? There's color coding of bins and color coding of the different standard orders to try to match visual inspection and get quality good.

AUDIENCE: We also color coded. So the red bin goes here. [INAUDIBLE]

ANNALISA WEIGEL: So they have three marks of color to try to get that all coordinated. Other best practices that won't come out again if you're just looking around?

AUDIENCE: Yes, we did a continuous delivery cycles up until we're done. Because we noticed that there was variability on how long it took to fill the bin. [INAUDIBLE].

ALLEN HAGGERTY: The Lean Aerospace Initiative, which funded all this stuff years ago, is the consortium of all the aerospace companies and the government. And in these conferences that we have, the suppliers, the engineers, the manufacturers would get up and make presentations to basically show how they do things. And that's the benefit of this-- makes the benchmarking a lot easier because people basically put their heads together and everybody benefits.

I mean there's an annual fee that the companies pay that supports all that. But they in fact get the advantages of-- gee, we took a tour through so many factory and they going a red light that goes on or something like that. So all the aerospace companies benefit from the conversation and the discussion and the presentations and the factory tours of each other's organization.

HUGH MCMANUS: The tools that they use include simple organization, which they can use lean principles like 5S and visual control to clean up their workplace. Just get the basic process working. OK? Balancing a workload. Which can be planned around lean principles like pack time, single piece flow. Which essentially allows them to move work between plants to clear bottlenecks and get the work balanced.

They can tear down or move facilities. Again, based on lean principles, not just random action. And they can modernize this archaic order system. Again, planned using lean principles. And there's a mechanic in the simulation to allow a paperless-- there's actually still a little bit of paper but much less-- ordering system that would simulate a modern web-based perhaps, or certainly electronics-based inventory management system.

One of the key features is the simulation allows us is to use data. It's very difficult to go out to a real aircraft manufacturing plant and play with it. With the simulation, we can play with it in these 12 minute rounds and create and use data that we've collected to both plan improvements and track processes. So we can keep track of how long does it take to do things? How many parts are involved? What's the delay involved in ordering parts, et cetera?

And we can do that quantitatively and that's one of the key aspects of most product improvement techniques. It's to use the data and let it tell you what to do, not just make things up as you go along. Be entirely dependent on common sense or experience to do these kinds of improvements.

And this data can be incorporated into classic lean tools like value-stream mapping. This is the same data plotted in the classic lean value-stream map. Again it gives them the opportunity to touch a tool, to actually use it, to actually fill out the data with data that they've collected from at least a simulated reality and then use that to analyze it, so that they can find bottlenecks. They can find non-value added steps. They can find places where paperwork and lack of synchronization are slowing the process down and then focus their improvements on those areas.

Finally at the end of the simulation, we essentially, as we do in the real world with lean thinking, ask them to expand their horizons. Expand the boundaries of the enterprise that they're considering and seeing if they can get bigger payoffs by doing more. By bringing in more functions. In this case, there's not an engineering function in the simulation, but we do allow them to redesign the airplane to cut part count. Reduce part types. Fix problems with the airplane. Make it easier to assemble. Do all of the things-- all of the engineering functions that facilitate lean in the real world.

And again, touch it, understand it, understand it in context, and then see how it works in the final round. And again, by rebalancing work, by redesigning the airplane, by changing the facility organization and further model modernizing the supply chain, by getting into a really clean modern just-in-time supply chain. Using the lean principles and implementing it on the simulation, they can get an outstanding process out of it. And that gives them a real intuitive and tactile feel for how lean type product improvement principles can be used to not just make a process better, but to make it astonishingly better in a way that they usually do not think is possible when they start the simulation.

Another thing that's done is throughout the simulation, we embed learning by doing mini lessons. And this is just a single example. Kanban systems. Kanbans are a inventory management ordering and transport system which is difficult to lecture to because it's a very simple thing that does a lot of-- that has a lot of different functionalities in the real world. And solves a lot of problems in ways that are sometimes not intuitive.

In the simulation, they use Kanbans to basically solve their inventory management and supply chain problems. And they get both repeated reintroduction to the concept and what they're doing, and mentored execution of that concept in the simulated world, so that they really do get an understanding of how a simple system like Kanban can serve so many functions and solve some problems.

The overall result-- and this is typical data from a real event is that they can go from producing no airplanes, or maybe one, the first time they try. To producing a dozen the last time, in the same time and using the same basic capabilities. They never get to throw the hourglasses away. It never turns into a LEGO building race. This isn't just a learning curve. What they've done is the process as it exists and made it much, much better. And tracking along with that is the financials, which go from losing a lot of money to making a lot. Not surprisingly, but again, they get a feel for how this kind of production efficiency can lead to financial performance.

OK, so we had a successful conclusion of our simulation exercise. All of our tables managed to produce at least eight aircraft. One table got all the way up to the 12 that the customer really wanted. And we had an 11 and a 10. Everybody got there by a somewhat different route and we learned some lessons along the way. Our group that produced eight. Now that was still better than the theoretical maximum six they were making before.

But they didn't meet the theoretical capacity of 12 because they still hadn't ironed out issues with their supply chain and with coordinating. It wasn't that they didn't have the theoretical capacity, it was that the coordination of the different components of their enterprise wasn't completely ironed out yet. So they didn't meet their production goals.

Very interesting. The group that made 11 airplanes did get everything coordinated. They did a very good job. One order. One order was one piece short. And in a lean system, you're very vulnerable to that kind of disruption. That one order. That one piece in that one order cost them an airplane, because it disrupted their synchronization. It took them a minute to recover. That was an airplane.

Still that is a known issue with lean production systems, not necessarily a bad thing. That the issue-- the problem that caused the one order to be bad was surfaced immediately. And in the future-- that happened actually early in the round and they didn't do it again. And of course they achieved 11, which is a lot better than seven aircraft. And we had one group that was hitting on all cylinders and managed to produce the aircraft a minute that the customers really wanted.

Interestingly too, if we look over the course of the whole day, the production-- a little bit of variation. Basically everybody's improving production as they go along. The financial results show some interesting detail. It's harder to see in the production diagram. Which is that although everybody's profit improved, people took different paths. And this has been a great class for this because basically the paths that people took pretty much mirror the kinds of things that can happen in the real world when you go into improvement events.

Group number one started out losing a lot of money. As soon as they stabilized their traditional process, they actually managed to make money. And when they disrupted it, trying to lean it out. They had what we call a worse-before-better. Things actually got worse until they got better again and stabilized at a high profit situation.

Group number two showed a much steadier increase in profit. They basically showed an almost linear improvement. So they were not so disrupted by change. Didn't come to quick results, but by learning slowly and steadily as they went through the transformation process, managed to increase their profits steadily. That's nice because that looks good. It's not always what happens.

The green te-- sorry, blue team, showed again, a typical reaction. They stabilized and then in the actual improvement round, the round where they changed things, showed at best steady financial results. So this was learning in a given state but they would have maxed out there. During the transformation they didn't make more money, but that set them up for the next round where they made a lot. And again during the next transformation they flattened off again. This is a lot nicer than that worse-before-better, but it's still very typical. While you're investing the resources. While you're changing things. You can't expect the dramatic financial results to happen right away. What you do is set yourself up for dramatic improvements in the next period.

And we had a final group which also did the worse-before-better thing. It had a little bit of a unfortunate end result, which is the very last round they actually had it worse. And that was the group that only made the eight aircraft. They were quite certain if we'd done another round that they could have gotten the 12 and in fact completed their zig-zag worse-before-better journey.

So that's a description of the simulation and how it's used. We're going to do a brief description of the pedagogical goals of the simulation and how we think they've been achieved in the Lean Academy context. We said that we wanted it to increase the comprehension of the curriculum. And there is some literature evidence that this works. In particular, in the computer world people have played computer games versus static computer websites. And it has been shown that the little games-- and these are little toy games. But the little games basically make people retain the material much better.

And also if you look at behavior. There's been studies on things like healthy diet that people that have learned through game-based learning as opposed to static learning actually take-- not only learn and retain the information, better but it actually affects the outcome. So that's good. That evidence is there.

We also hoped that there's better understanding of the context and the holistic nature of the material. And we hoped that they learn through experience. That it engages different learning modes and that it allows them to practice field, to actually touch and use the ideas. These are supported as goals. But there's not really a whole lot of scientific evidence that this works. Intuitively, the evidence is pretty powerful and the anecdotal experience from the students is powerful. It's not a proven outcome. And we can certainly say that we've observed greatly increased student involvement and excitement.

AUDIENCE: Yeah, when we were on the same team for the LEGO simulation and it was a lot of fun. Especially since we got a little competitive with the other teams and trying to build the most airplanes. But that was really cool. It's something that we played with ever since we were little kids and to be able to build something but then apply the lean principles. And it was really amazing to see how much we learned through that.

AUDIENCE: It was probably the best way of demonstrating how process that I thought it was efficient at first and after applying lean. We didn't think we could make 12 airplanes in 12 minutes but well-- we almost made it. We made 10. But it is possible to do what some believe is impossible at first. And after applying the analysis and getting all the processes down correctly, we were getting pretty close.

AUDIENCE: Yeah, I mean that's pretty amazing. I was looking at the chart up there and I was like, wait. We really only made one in 12 minutes the first time? And then went all the way up to 10 so.

AUDIENCE: We're impressed.

AUDIENCE: Yeah.

HUGH MCMANUS: So we think this is working. We also have had very positive experience with basically teaching complicated systems. Most of the previous literature evidence was on relatively simple things. Fact-based things. We're actually trying to teach a system that affects other systems. So it's a complicated body of knowledge, body of understanding, that the students are expected to absorb in a relatively short time. And most of these systems are not available for manipulation for teaching purposes. You can't go play with an airplane factory.

We found that the students have a good experience-- and this experience is not limited to this particular simulation, although this is a good exemplar of it. If the simulation is complex enough to capture the key features, including the emergent behaviors of the system. If it's too simple, you're not really changing anything. You're not really changing a system that has unexpected behaviors, so you're not going to capture this kind of learning.

On the other hand, it has to be simple enough to have an acceptable learning curve. If it takes three days to learn it's not going to be a teaching tool. And of course, it has to be fast enough that you can do multiple cycles of learning within the teaching period. It also has to be credible in the sense that it can't have artifacts that the students say, well, this is not realistic and therefore I will dismiss the experience because I don't believe it. And it has to be fun to keep people engaged. And basically on this set of criteria, we think that the simulation that we use in the Lean Academy is pretty good.

Students think it's pretty good too. This is feedback from about 200 students, 194 students over a couple of years of Lean Academies. And we consistently get the highest score of the types of learning, both other active learning and lecturing materials. That the Lean Academy simulation provides positive reinforcement of the concepts. That's the wording of the question and the students agree that that's the case.

Just qualitatively we also get some written feedback and verbal feedback. And it appears, and again this is unprompted. We asked them the general question, what do you like about the course and what do you don't like? And what we find is what they like is what we're hoping, which is that it increases the comprehension of the curriculum. That the hands-on learning and practice field experiences are valuable to them. And that it increases their involvement and excitement with the material. As well as-- this was not an explicit, but it does show up a lot in the student responses as a team building and camaraderie building activity. It's also very effective.

And this is just a numerical breakdown of those kinds of responses. Out of 106 written responses, we got a lot of illuminatings. A fair number of, we liked the hands-on aspect. And the excitement and bonding were somewhat secondary but mentioned. As well as a big blob is just generic, we like it. But that doesn't tell us a whole bunch about why they like it but these do and it's what we're hoping.

Caveats. Always important. This evaluation is based on satisfaction, not really outcomes. We don't track the students in their careers as aerospace engineer so we don't have outcome metrics yet. It's cost and time intensive to do this kind of thing. You need trained facilitators. It takes money to set up a facility to do this, couple of thousand dollars. That's the startup cost. Not the per each, although you do have to pay these people somehow.

They're vulnerable to disruption. Logistics, facility, failure to keep on schedule errors can degrade the experience badly. Our simulation seems to be fairly robust but in general simulations are vulnerable to disruption. And you can't satisfy every learning style. Amusingly, we've had written feedback asking for both more and last simulation. Because some people feel they need more time to internalize the information that's there. Others get it quickly and wish they could move on to other learning modes.

And another one, and it's a unexpected psychological effect, is that there's real stress in the simulated process. And that this sometimes creates difficulties with people's learning. Could create competition and bad feeling if it's not managed carefully. We've learned that that's something that is an issue that needs to be managed. And these, by the way, are typical issues for teaching simulations.

Conclusion to this part. We have a unique simulation of aerospace enterprises. A subset of it is used in the Lean Academy. We think it works and it provides a laboratory for experiential learning of complex systems. There's not a whole lot of work in this area going on. We've had a very good experience with it. Certainly the feedback that we have from our students indicates that it's successful. And the caveats that we have for our simulation are typical of learning simulations in general.

ERIC REBENTISCH: There are other aspects of the simulation that replicate the entire enterprise and I'm going to talk a little bit about each of those elements. And the simulations are modular so you can go through the manufacturing part or you can go through the engineering part, depending on what the learning objectives for the course are. You can combine them in various ways. You can combine the manufacturing with the engineering to teach specific lessons about transition to production and engineering support. You can look at just engineering alone if you are interested in understanding how engineering processes behave in a highly variable environment. So there's a lot of flexibility that's built into the simulation environment.

So this is the simulation that you all experience here in the Academy that has a manufacturing core simulation and a simplified supplier base with a representative. If you expand out to the full supplier simulation, you get a much richer experience of understanding how ordering and fulfillment processes are dynamic in the enterprise. And learning much more about network organization structures and the way they behave and how effective coordination is critical to lean.

For the full enterprise, you can add the dynamics of an engineering system that is supporting the manufacturing and supply base. And this is the full [INAUDIBLE] sim, where the engineering changes that you made during the course of the redesign of the airplane were done for essentially free in this simulation that you did in the Lean Academy. In the real enterprise simulation, you have to wait for the engineers to process those jobs. And that can lead to all sorts of interesting dynamics amongst the players and simulated organizational structures.

There's also a service and support module that looks at aftermarket field support for the products and this introduces new and interesting complexities to the enterprise. Because you now have two main value streams and sources of revenues. You have to prioritize where you make improvements in the enterprise.

All right. So there's another variant of the simulation that focuses on just an engineering organization. Most engineering organizations have multiple projects going on at a given time and they're competing for resources. And those projects aren't always the same. So this simulation looks at how you prioritize projects, how you structure the organization, how you manage the interactions so that you get the highest throughput through the system and the most return on investment for improvements through lean practices.

So some of the things that we're not covered in the Lean Academy simulation are a more advanced economic system that allows you to make trade-offs, to understand what the impact of lean improvements are, and to actually calculate financial performance of the kind that you would typically track with a real company. There's also a lean calculator that can be used to evaluate whether one proposed improvement effort is better than another. And these are levels of analysis that are more in-depth tools, that are more sophisticated that can be added on to the sim environment. So in all, it's a fairly sophisticated system for teaching the impact of lean principles and practices on an enterprise.

So there are a number of organizations that are using the web simulation and its variants and they have adopted it for their own use and are actually using it in their own internal training. So we have a method for actually disseminating these materials. And if there are any questions about adopting the simulation, the best place to go would be to send a message to ednet@mit.edu. And you can get more information about how you might adopt these training materials.