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TEACHING UNIVERSITY STUDENTS THE LAST PLANNER SYSTEM THROUGH LEARNING-BY-DOING

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ABSTRACT

Using games and simulation have long been a staple in teaching lean construction. While such games work well for teaching narrow concepts and ideas, they struggle when it comes to teaching all of the complex interactions found in the Last Planner System (LPS)

This paper describes the development and implementation of a new approach to teaching university students LPS. Rather than using games or simulations, the students were tasked with using LPS to plan and manage their work on the course assignments.

The developed approach led to a superior understanding of LPS than what was previously seen in the course where it was implemented.

KEYWORDS

Lean construction, last planner system, teaching

INTRODUCTION

Construction education has increasingly focused on active learning over the past decade (Aliu & Aigbavboa, 2021). However, related to lean construction, this is not a new trend. For example, using serious games and simulations in the classroom has long been a staple in teaching lean construction (see e.g. Tsao et al., 2013).

According to Rybkowski et al. (2021), lean games and simulations provide *"the type of controlled laboratory conditions that are usually found in the physical and biological sciences where the impact of a single variable is tested and measured between rounds of play."* While the benefits of lean games and simulations are many, I would argue that the previous statement hints at a limitation of the typical games we employ in our community – the focus on a single or few variables at a time. In my experience, these games and simulations excel in teaching limited concepts and theories – for example, batching, variability and buffers, or push and pull – but can fall short in teaching more complex interactions—case in point – the last planner system (LPS).

LPS is a methodological framework for project planning and control (Ballard & Tommelein, 2021). It has several primary components: project execution planning, master planning, phase planning, lookahead planning, weekly work planning, and learning. Several games and simulations exist for teaching LPS. However, in my experience, teaching the interplay between all the LPS parts using a game or simulation is challenging.

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I have used Villego as an aid in teaching LPS for several years. Villego is an LPS simulation based on teams of 6-14 participants constructing Lego buildings (Warcup & Reeve, 2014). The simulation has two rounds. The first round relies on a traditional planning and control approach, and the second round uses LPS methodology. As far as lean simulations go, Villego is one of the most time-consuming ones, requiring at least four hours of class time.

While Villego is an extensive and comprehensive simulation, it has been my experience that it fails to teach LPS thoroughly. It covers certain LPS aspects well – such as pull planning and weekly coordination meetings. However, I have found it lacking in teaching other aspects. In particular, the students do not learn much about the different plan levels, constraints, or constraint removal through the lookahead process. In Villego, one plan functions as a mashup of a phase schedule, lookahead schedule, and weekly work plan. And while the student, to some extent, will discuss constraints during the game execution, there are no elements of formal constraint analysis.

As part of a comprehensive redesign of the assignment and assessment scheme in a course where I taught LPS, I decided to rectify this shortcoming in my teaching approach. One approach would have been to expand on the base Villego game. However, this would have led to significant logistical issues. Expanding the game would have led to splitting the game over several class sessions or having longer sessions. Considering I already had difficulties getting assigned room for these sessions, doing so was not an option.

Another option was to consider other games and simulations that purportedly better cover the missing pieces. (e.g. González et al., 2014). However, I chose to go in another direction. Instead of simulating using the last planner system in a serious game, I would have them learn LPS by using it throughout the semester to plan and manage their course assignments.

This paper aims to describe the approach I took in the course and its experiences. First, the paper describes the methodology – the teaching approach and how it was developed, and how I gathered data to document the experiences. After that, the paper presents results and experiences using the described LPS teaching approach, including the significant challenges and issues identified during the semester. Finally, the paper concludes that the approach is a sound concept, but there is much room for improvement in the implementation.

METHODOLOGY

This section describes how the new teaching approach was developed and summarizes the approach. The teaching approach was developed and introduced as an integral part of a new assignment and assessment scheme 7.5 ECTS credits elective course taught in the spring of the third year of a five-year integrated master's program. The LPS assignment was tightly interwoven with the rest of the assignment scheme. Therefore, to properly discuss the approach to teaching LPS, this section will first present some background about the course and the reasons for changing the existing assignment and assessment scheme.

CREATING A NEW ASSIGNMENT AND ASSESSMENT SCHEME

To help develop the new assignment and assessment scheme, I hired one of the students who had just taken the course as a teaching assistant. She did most of the work developing the new assignments based on my overall ideas and guidance.

The overall idea of the assignment scheme was to move from traditional assignments and school exam to portfolio assessment. At the end of the semester, the students would turn in a portfolio consisting of group assignments and individual reflection memos on the students' experiences participating in the lean games and simulation. I introduced the reflection memos to incentivize the students to participate in the lean games. However, as these did not have any relationship with the LPS teaching approach, the paper will not discuss these any further.

At the outset, the idea was that the course would have a group assignment for each of the topics taught in class. However, it occurred to us early that having all of these assignments be mandatory would result in a too high workload for the semester. Therefore, the teaching assistant and I decided to have three mandatory group assignments and a pool of elective assignments, of which the student would have to choose two. The idea behind the elective assignments was that for the students to choose which assignment they wanted to do, they would have first to attain some notion of the subject matter.

The assignments were mostly independent of each other. The only exception was two of the mandatory assignments. In one assignment, the student groups had to map out what value factors would be important for each group member when buying a home. In another assignment, each member first had to find and nominate a home currently on the market, and then the group had to use Choosing by Advantages (CBA) to select an identical home for all of them. It was encouraged – but not required – that the groups used the value factors mapped out in the first assignment as factors in the CBA analysis.

Most of the assignments had the groups using A3 reports. Sometimes with additional documentation. For example, the groups had to turn in an A3 report, a complete CBA form, and a two-page memo of the groups' experience with the process for the CBA exercise.

DEADLINES

With regards to deadlines, we took a novel approach. There were no fixed deadlines for the assignments. Instead, each group would decide when to hand in their assignments – with some restrictions. The groups could only submit one assignment per week for comments and approval. If an assignment had failed to receive prior approval, it would only count for 50% of normal if a student included it in their portfolio. We chose this approach partially to force the student to work more evenly throughout the semester and partially to put them in an environment where they need and benefit from using a planning method such as LPS.

LPS AS AN ASSIGNMENT AND AN ASSIGNMENT FRAMEWORK

We incorporated LPS both as an assignment in and of itself and as a framework for the other assignments. The students would use LPS to plan and follow up on the group assignments. At the end of each week throughout the semester, the groups would submit a report of their LPS usage. This LPS report consisted of their weekly work plan for the following week, their weekly work plan for the current week – with PPU and reasons for non-completion, their lookahead schedule for the following three weeks, and their phase schedule – if they had updated it. To enable the student's LPS use, we created a simple Excel spreadsheet that they could use.

As an aid for the groups' continuous improvement work, we had them do a team evaluation twice during the semester. The evaluation was based on Lencioni's (2002) five team dysfunctions: Absence of trust, 2) Fear of conflict, 3) Lack of commitment, 4)

avoidance of accountability, and 5) Inattention to results. The dysfunctions take the form of a pyramid where lower-level dysfunctions are a cause of the higher levels ones. For example, lack of trust leads to fear of conflict.

In addition to group work on LPS, as part of the portfolio, the students also had to include an individual two-page reflection memo on how they had experienced the LPS process.

LIMITATIONS OF LPS IMPLEMENTATION.

While the idea was to give the students a more complete experience of working with LPS than what can be achieved through simulations like Villego, we did elect to have a somewhat simplified LPS implementation. We included no aspect of project execution planning, as this is taught in other courses in the master's program. In addition, we did not let the students do any milestone planning themselves; instead, we handed them a predefined milestone schedule at the beginning of the semester.

Of the five metrics now typically used in LPS implementations (Ballard & Tommelein, 2021), we only included Percent-Plan-Complete (PPC) and Frequency of Plan Failures.

LECTURES AND LECTURE SCHEDULE

While the assignments and assessment scheme were wholly revised, I left the lectures and lecture schedules mostly unchanged, including the lean games. The only notable exception was the addition of a startup workshop In the first week of the semester. Here, the students were organized into groups, given a cut-down lecture on LPS, and tasked with creating the group's phase plan for the semester.

SUMMARY OF LPS TEACHING APPROACH

- LPS used as a framework for managing group assignments throughout the semester
- Each group had 4-5 members
- The groups had to hand in an LPS report each week consisting of:
    - Revised phase schedule
    - Weekly work plan for the current week with PPC and reasons for non-completion.
    - Weekly work plan for the coming week
    - 3-week lookahead-schedule with constraint analysis
- Teaching assistants checked and gave feedback on LPS reports
- Student groups carried out two team evaluations during the semester
- Each student had to write a two-page reflection memo as part of the final course folder.

DATA GATHERING AND ANALYSIS

Gathering data on how well the teaching approach worked was done in two steps. First through observation throughout the semester by myself and two teaching assistants. This observation was *ad hoc*. We had no observation guides or tools typically applied in more formal observations. In addition to the observational data gathered throughout the semester, I analyzed the final folders that the students handed in. In particular, the groups' LPS spreadsheets and the individual LPS reflection memos. I imported all of the 39 LPS reflection notes into the computer software Nvivo for thematic analysis.

Since the folder assessment differed widely from the school exam used in previous course iterations, making rigid benchmarks like comparing grade outcomes would be difficult. Therefore, assessing how well this teaching approach had achieved the desired learning outcomes relied on subjective expert opinion. Using qualified experts' opinions has been shown to provide very accurate assessments when statistical data is not available (Vanston & Vanston, 2004). While it is preferable to rely on a panel of experts, this was unfortunately not possible in this case – myself being the only person having sufficient knowledge about the students' previous performance in the course.

RESEARCH LIMITATIONS

I did not plan from the beginning to carry out research on the new LPS teaching approach. Doing so was more of an afterthought. The data I gathered during the semester was for continuous improvement of the course, not for research and publication. Thus, I did not do any structured data gathering about the student – for example, their educational background and previous knowledge – beyond what I gathered during a normal course execution. Nor did I make any attempt to benchmark the students' LPS knowledge gained through the course related to the previous, more traditional version of the course.

The evaluation of the teaching approach's efficacy in teaching the students LPS rests solely on my expert judgment. I have tried to be as honest and objective in my assessment; However, there is always a possibility of unconscious bias – especially since I am evaluating something I myself created. Thus, while I later in the paper argue that the teaching approach worked well, the evidence for this is somewhat tenuous. A more stringent test protocol would need to be devised to properly assess how well this teaching approach works versus more traditional approaches. However, I would argue that this research still provides adequate proof of concept of the feasibility of this teaching approach.

RESULT AND DISCUSSION

This section presents results and experiences using the described LPS teaching approach, including the significant challenges and issues identified during the semester.

OVERALL RESULTS

The students reported varied experiences using LPS to manage the work on the course assignments. While most of them reported gaining an understanding of how LPS works and is beneficial in construction projects, they were diverse in their opinion on how they had experienced it using it themselves. Some were very enthusiastic, expressing that they would continue using LPS for group assignments in other classes. However, others expressed that they had experienced LPS as complete overkill for managing the coursework – the effort they needed to use LPS vastly outstripped the benefit they had from it.

This divide seemed to stem from personal preferences mostly. The students who liked using LPS typically voiced a strong preference for having highly structured work, while those who found LPS to be overkill preferred more ad-hoc approaches. However, most of them who found using LPS overkill still acknowledged that it would be beneficial to use LPS on construction projects.

The students' comments suggest that I should have communicated to them more clearly the intent of using LPS in the course. It was not primarily to make it easier for them to plan and control their work but instead to learn LPS.

Based on the semester's observations and the reflection memos' analysis, the teaching approach worked reasonably well for teaching them LPS. The students gained a better and more in-depth understanding of LPS than seen in previous incarnations of the course. However, still not as good as desired. As pointed out later in this section, there is significant room for improvement, discussing issues and challenges identified during the semester.

OPEN-ENDED ASSIGNMENTS AND ASSIGNMENT SCHEME

One issue I had not considered when designing the assignment scheme was the students' ability to handle its open-endedness. The first two years of our master's program courses contain primarily engineering fundamentals such as math and physic. That is, courses where they get clearly defined problems on a silver platter, which they employ "cookbook" recipes to solve, with one absolutely correct answer, with a specified deadline. Therefore, it was challenging for the students to define their own problems with no clear solution path, no objectively correct solution, and no set deadline. The students were mentally unprepared to tackle many of the assignments they saw in this course.

Many of the students reported feeling overwhelmed at the beginning of the semester. They had no clue how to tackle not having fixed deadlines for the assignments. However, most of them noted that they had managed fine when they got over the initial shock and started planning out the work to be done.

While I believe that the students should be taught to handle open-ended problems from the beginning of their studies, my influence on the overall study program is limited. However, introducing the concept of open-ended problems at the begging of the semester – through lectures, discussions, and games – should remedy the worst of the mental shock that some students experienced.

PHASE SCHEDULING

Phase scheduling within LPS is typically done with pull planning. However, since pull planning was not on the lecture schedule until a few weeks into the semester, I elected to have the groups create the first phase scheduled through more traditional means. I based this choice on the assumption that they already had some rudimentary knowledge of project scheduling. Unfortunately, this assumption proved to be wrong. The students had not encountered any form of formalized planning in previous courses. Nevertheless, through some guidance, they could still create passable phase schedules. In hindsight, it would have been better to rearrange the lecture schedule and teach them pull/planning from the get-go.

LECTURE SCHEDULE

The previous issue shows that it was a mistake not to rework the lecture schedule and lectures. My original thinking was that the students would learn LPS by using it as they went along throughout the semester. However, as previously pointed out, this thinking assumed they had more previous project planning knowledge. In hindsight, I should have given them a thorough introduction to the subject matter before throwing them in at the deep end. Thus, I will include more project planning and control material in future iterations at the beginning of the semester, including moving up the LPS lectures and the Villego simulation.

Another issue with the lecture schedule was that it was too crowded. There needed to be more room to have class discussions and make clarification on the last planner use. The student groups got weekly feedback on their LPS reports from teaching assistants.

However, these were insufficient in clearing up some common mistakes and misconceptions – for example, misunderstandings about constraint types as described later in this paper.

LOOKAHEAD PLANNING AND CONSTRAINT ANALYSIS

One of my primary reasons for using this approach to teaching LPS was better to teach the students about constraints and the lookahead process. This approach did give the students a better understanding of these topics; however, not as good as I had hoped.

The students themselves expressed differing opinions about the lookahead planning and constraint analysis. While most found it helpful to enable them to identify and remove constraints in advance, some expressed that it had been more or less a useless chore as they had no real constraints.

Most of the students expressed that they found identifying constraints difficult. This problem was also evident in their weekly LPS reports. I identified two main underlying issues as to why constraint identification was difficult for them. First, the work to be done was inherently too unconstrained. The different mandatory and elective group assignments were, for the most part, unrelated. That is, they were free-standing exercises with no constraints between the tasks. Also, few of the tasks were of a sufficient size that would yield many internally constrained sub-tasks

Second, the students were unable to identify constraints that were there. An industry practitioner in a construction project will identify constraints based on their experience doing the same or very similar tasks. Students can and will do the same to a certain extent. However, they are limited constraints related to their generic experiences with group tasks - such as booking a meeting room for the group to do a task or their availability to do a task. They lack the domain knowledge to detect issues with the task itself without starting to do it.

I had naively hoped that this is what they would do just so – to start doing preliminary work on the task, way before the date they had planned for the assignment to be finished, to sufficiently understand what they would need to complete the task. However, unfortunately, the students did no such thing. Instead, they would block out a day or two for doing the assignment on the plan and not look at it until this date.

For example, one group assignment entailed creating a takt plan based on a case description. This case description had – unintentionally – ambiguous and missing information. None of the groups flagged this as a constraint in the LPS process. Indeed, very few groups even raised questions about the insufficient information during the task execution – most of the groups relied on making-do and made assumptions rather than pausing the task to get clarification.

The takt planning example also relates to another issue of task identification – the groups focused too narrowly on their own work. They were mostly blind concerning external issues, like problems with the assignments. Another example: for some of the possible weekly assignment submissions, I had forgotten to create the submission in advance in the learning management system (LMS). No group ever identified this as a constraint in advance, but many would contact me right before the deadline to get me to do so.

In addition to having problems identifying constraints, many students struggled to classify correctly the constraints they did identify. For example, most groups reported constraints and reasons for non-completion related to assignments in other courses. I would argue they should have classified these occurrences as labor constraints. The

groups could not do the work because their laborers – the students – were tied up elsewhere. However, many groups did not categorize this as labor constraints but external condition constraints.

The student's inability to classify constraints correctly is not due to any weakness of the LPS teaching approach. Instead, the teaching approach here exposed a failure to give the students a sufficiently good understanding of the topic from the related lecture and the course literature. Applying LPS to their own work illuminates their understanding of the topic in a matter that the more traditional school exam never could.

For future iterations of the course using this teaching approach, introducing more constraints into the assignment work is of primary concern. One possibility would be to build upon the accidental constraints that were introduced; the missing and erroneous information in the assignment texts and the late posting of submission links on the LMS.

To incentivize the students in identifying these constraints, their ability to do so could be considered in the grading. However, doing so could be a tricky balancing act. Since the students have limited prior knowledge of the tasks they are embarking on, they will often not be able to identify constraints such as missing information until the task is well underway. Therefore, grading their ability to identify constraints could lead to them making shadow plans and completing the task before the tasks go onto the official plan, enabling them to identify constraints after the fact.

Another option for introducing more constraints would be to create more interlinked assignments and possibly interlink the groups. For example, there was a weak link between the assignments on value and CBA. The groups were encouraged – but not required – to use the output of the value assignment as the input to the CBA assignment. Making doing so mandatory would create a hard constraint between the assignments. Furthermore, instead of having the groups use their own work, they could be tasked with using the results from another group.

WEEKLY WORK PLANNING WAS TOO EASY

It became evident early on that that weekly work/planning was too easy – within the parameters we had given the students. I told them to plan within standard LPS guidelines. That is, no activity should span across weeks. The problem was that the students would allocate three days to a task that might take two hours, and there was no issue for them getting it done during this time frame. This problem occurred partially due to unclear instructions; however, a significant underlying challenge is that the total assignment workload was too low to make planning the execution of it a challenge at the week level. I partially remedied this issue by specifying that no assignments should span more than a day.

Another reason – for the work planning being too easy – is that most of our students have a high degree of flexibility in their lives. For example, they might have programmed lectures, but we do not require that they attend them. Moreover, they often have few other obligations. For example, they seldom have family obligations and have no qualms about using nights and weekends to get work done.

In addition to students individually having a flexible schedule, the groups had too much internal flexibility. That is, there was a lack of skill diversity in the groups. All the students have the same skill set and could perform all the tasks. Thus, if one of a group's members could not do any work – e.g., due to becoming sick – any of the other group members could easily pick up the slack. This situation is very different from what one will encounter in a construction project, where different trades have specific skills needed

for specific tasks. The task of wiring a circuit cannot be shifted over from an electrician to a plumber.

It could be possible to design group assignments where the different group members are assigned specific roles and tasks – similar to what we often do in Lean simulations like Villego. However, I fear that the roles would be difficult to enforce without the active oversight from a facilitator – not possible in this teaching approach. Thus, I would argue that a better option is to have different groups have different roles. That is, having the groups be dependent on each other, as previously discussed.

TEAM DYNAMICS

In general, the groups worked well together. Some groups had initial issues with working together but could identify and handle them as part of the team evaluation process. For example, several groups reported having issues due to different ambition levels among members – for example, group members who were content with just passing the course would skip group meetings. The group evaluation processes gave them an avenue for bringing the matter to light.

In hindsight, I should have had the groups create conditions of satisfaction for themselves at the beginning of the semester. Doing so would have brought up issues like different ambition levels at a much earlier stage

FACILITATION

As all lean educators know, good facilitation is a key to success when running lean games and simulations. However, in this case, the groups did receive facilitation in the traditional sense of having a facilitator lead them stepwise through the process.

After the initial startup workshop, the groups were left more or less to their own devices to start using LPS and hand in their first LPS report. They then received comments on their weekly reports from the teaching assistants through the LMS. In addition, the student assistants and I held weekly supervision sessions where we were available to help the groups might with any of their assignments, including the LPS reports.

The described efforts worked reasonably well in steering the groups in the right direction; however, a key component was missing. In addition to providing feedback and help to each group individually, it would have been beneficial to have plenary discussions at several points throughout the semester – i.e., to facilitate the kind of guided reflections that are typically part of lean games and simulations. However, as previously mentioned, the existing lecture schedule did leave room for them.

LEARNING BY DOING VERSUS VILLEGO

I would argue there are two main benefits of using the learning-by-doing approach described in this paper versus Villego: 1) the time horizon and 2) the fidelity of the LPS implementation.

While Villego is one of the most time-consuming lean simulation games, it is still run over a very short time horizon – typically one 4-5 hour session. In the learning-by-doing approach, the students use LPS throughout an entire semester. The benefit of doing so is that they can absorb and mature the knowledge piecemeal over time. LPS is a complicated system with many moving parts. Absorbing it all at once is hard, especially for university students with little to no practical experience to serve as anchor points for the knowledge.

Regarding the fidelity of the LPS implementation, Villego uses a very simplified version of the LPS. There is only one plan. This plan functions as a mashup of a phase

schedule, lookahead schedule, and weekly work-plan. Thus, Villego gives a limited feeling of LPS as a concrete tool. This simplification is necessary due to the time horizon Villego is run within. While the learning-by-doing implementation this paper reports on also made several simplifications – for example, PPC was the only metric used – running a semester-long exercise allows for a full-on LPS implementation. The limiting factor here would be software. While the Excel workbook I made worked well enough for the current implementation, a full implementation would likely require moving from Excel onto more dedicated software.

While I would argue that the two described benefits are significant, that is not to say that Villego and similar simulations do not have a function in teaching LPS. They can work well for introducing the fundamental concepts embedded in the system. In real world practice, Villego might be used to teach LPS to practitioners immediately before they will start with actual use on a project. From the learning-by-doing in real life, they attain tool skills and cement the concept they have been introduced to with Villego. For university students, the situation is very different. There might be years from when they learn LPS at the university until they encounter it in practice and can start to learn the tool skills. Hence, it is beneficial for them to practice something very close to actual LPS use. However, LPS simulation games can also function here as an excellent first introduction to the concepts and ideas behind LPS.

CONCLUSION

This paper has described and discussed a new approach for teaching LPS to university students. I would conclude that the approach works at the conceptual level; that is, it is beneficial to have students use LPS over an extended period to plan and control some work. However, the practical implementation could have been better. Some of the issues were minor and easily corrected in the future. For example, to tweak the lecture schedule and add conditions of satisfaction for the groups. However, other issues require a more fundamental redesign of the implementation. The most significant issue is that the work done for the students was too unconstrained for various reasons. This issue will likely require something more than minor tweaks.

In described course implementation, the students used LPS to plan and manage their course assignments. Another option could be to go back towards simulation but have it as a semester-long affair instead of just a single class session. Doing so will likely require the simulation to be performed on a digital platform. It is unlikely that the university would allocate me room to run a semester-long lego-building exercise. I am currently exploring using the game Minecraft as a platform for this purpose.

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