Developing competencies in IT project estimation: A simulation-based training using LEGO®

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ABSTRACT

Accurate estimates of the scheduling and functionalities of information technology (IT) projects are essential. However, making accurate estimates is challenging, as estimators may lack the necessary historical data, experience, methodologies, knowledge or skills. Students enrolled in IT and project management courses need to be made aware of the challenges, obstacles and key elements of estimating, namely the need for rich, high-quality information and appropriate expertise and experience. To support the acquisition of estimation competencies, we combined the affordances of simulation-based training (SBT) with those of the LEGO® bricks to develop and test a project estimation SBT. We explain why LEGO® bricks were used and present a general description of the simulation's modalities. In addition, observations and data collected from 123 undergraduate students enrolled in the "IT Project Management" course at a North American university over four semesters are presented. The results show that students had a positive and enriching learning experience. In terms of educational validity, the simulation provides a realistic representation of the real-world business environment where students can develop their estimation competencies and know-how through learning by doing.

Keywords: *IT project management, estimation, experience-based learning, simulation, LEGO®.*

RÉSUMÉ

Des estimations précises des fonctionnalités et du calendrier de projet en technologie de l'information (TI) sont essentielles. Par contre, l'établissement d'estimations précises est ardu puisqu'il arrive que les estimateurs manquent de données historiques, d'expérience, de méthodologies, de connaissances ou de compétences pour estimer. Dans un tel contexte, les étudiants inscrits aux cours en TI et en gestion de projets doivent être sensibilisés aux défis, aux difficultés et aux éléments clés de l'estimation, c'est-à-dire avoir une information riche et de qualité ainsi que de l'expertise et l'expérience appropriées. Afin de soutenir l'acquisition de compétences en estimation, nous avons combiné les avantages de la formation par simulation avec ceux des briques LEGO® pour développer et tester une simulation en estimation de projets. Nous expliquons pourquoi les briques LEGO® ont été utilisées et

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présentons une description des modalités de la simulation. Les observations et les données recueillies lors de quatre trimestres, auprès de 123 étudiants inscrits au cours « Gestion de projet TI » dans une université nord-américaine, sont présentées. Les résultats montrent que les étudiants ont vécu une expérience d'apprentissage positive et enrichissante. En termes de validité pédagogique, la simulation fournit une représentation réaliste du monde des affaires dans lequel les étudiants peuvent développer leurs compétences en estimation en apprenant par la pratique.

Mots-clés : *Gestion de projets TI, estimation, apprentissage expérientiel, simulation, LEGO®.*

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1. INTRODUCTION

Nelson and Morris (2014) recently reminded us that "despite a great deal of attention in the trade and academic press, IT projects continue to fail at an alarmingly high rate. One of the most-cited reasons for these failures is poor estimation practices" (p. 14). Generating accurate estimates of the schedule and functionalities of information technology (IT) projects is essential as it facilitates better scheduling and monitoring; supports the selection and evaluation of project team members; helps project teams develop their credibility; minimizes the "late-in-the-project discovery" (Nelson & Morris, 2014, p. 16); diminishes the probabilities of riffle effects; decreases possible vicious cycles (more stress means more mistakes, which mean more schedule slippage, which means more stress); and helps assess projects' success (Basten & Sunyaev, 2014; Nelson & Morris, 2014; Schwaber & Sutherland, 2017; Shmueli, Pliskin, & Fink, 2016). However, IT project estimators[4] do not seem to be very good at their task, as too many IT projects still experience budget and time overruns and missing functionalities (Standish Group, 2016).

IT project stakeholders prefer accurate to inaccurate estimates as the latter are likely to engender stakeholder dissatisfaction and false expectations (Nelson & Morris, 2014). Producing accurate estimates is challenging for IT project estimators as they sometimes lack historical data, are pressured by stakeholders to modify their estimates, lack guidelines or a methodology for estimating, lack the requisite knowledge and skills, do insufficient analysis before generating their estimates, etc. (Armour, 2002; Jorgensen, 2004; Shmueli *et al.*, 2016). However, collecting relevant information when estimating can reduce uncertainty and help generate better estimates.

Accurate estimates come with a cost, both in time and money, as improved accuracy requires greater efforts, access to rich, relevant information, and appropriate levels of experience and expertise (Basten & Sunyaev, 2014; Jorgensen, Boehm, & Rifkin, 2009; Morgenshtern, Raz, & Dvir, 2007). Moreover, in IT projects, estimates are made to help managers reduce the risk of delivering unsuccessful projects but, too often, these estimates are made in a rush without proper information, technique or experience (Woo, 2018). As estimation expert Amanda Woo (2018) reminds us, "honest, credible and accurate estimations are a much harder task than we perceived them to be, especially if you've not done them before or never received formal training on how to do estimations."

[4] Estimators are the individuals or groups of individuals responsible for creating IT project estimates. They may include team members, project managers, Scrum masters, technical leads, business managers, product owners, etc.

In this context, students enrolled in IT and project management courses must be sensitized to the challenges, difficulties and key elements of estimating (Armour, 2002; Jorgensen *et al.*, 2009). They need to understand (1) the importance of information quality and richness and (2) the key role expertise and experience play when making estimates. This is particularly important because expert estimation is the most frequently used method and one of the most useful approaches for estimating in IT projects (Jorgensen, 2004; Jorgensen *et al.*, 2009).

To support the development of estimation competencies and introduce students to the challenges associated with estimating in IT projects, we developed and evaluated a project estimation (PE) simulation-based training (SBT) using LEGO® bricks. More specifically, our main research question is: What pedagogical approach can be deployed to help novice estimators develop estimation competencies? Two sub-questions flow from this main question: (1) How can we increase novice estimators' awareness of and sensitivity to the importance of quality information and experience in estimating? (2) Can an SBT approach, combined with the affordances of LEGO®, create impactful learning experience for novice estimators?

This paper describes the PE-SBT's objectives and discusses its potential for teaching and developing estimation competencies. The first section defines and contextualizes IT project estimation, explains the central role of the play concept, describes SBTs and explains why LEGO® bricks were used. Then an overview of the PE-SBT's modalities are presented. Finally, observations and analyses of data collected from four PE-SBT sessions with 123 undergraduate students enrolled in the "IT Project Management" course at a North American university are presented and the literature on estimation is used to highlight key contributions.

2. ESTIMATION IN IT, SIMULATION-BASED TRAINING, PLAY AND LEGO

2.1. Estimation in IT

Estimates are part of our everyday life; they are central to IT projects as they help minimize risk, increase predictability and make better informed decisions (Tanveer, Guzmán, & Engel, 2017; Trendowicz & Jeffery, 2014). In IT projects, estimating, which can be defined as "an informed assessment of an uncertain event" (Nelson & Morris, 2014, p. 16), is usually done using top-down approaches, such as consensus methods, ratio methods, apportion methods and function points, or bottom-up approaches, such as template methods, parametric procedures and range estimating (e.g., Azzeh & Nassif, 2018; Larson & Gray, 2011; Morgenshtern *et al.*, 2007; Whigham, Owen, & Macdonell, 2015). However, too many estimators still establish their estimates using intuition, guessing or personal memory (Nelson & Morris, 2014).

Future IT project team members, analysts and managers will have to make estimates based on information of variable quality and richness while ensuring that their estimates are used properly to select, plan, monitor and manage IT projects. Moreover, in recent years, the Agile Manifesto and Agile methodologies/frameworks such as Extreme Programming, Kanban, Crystal and Scrum have spread, changing how IT projects are deployed and executed (Dybå & Dingsøyr, 2008; Schwaber & Sutherland, 2017). Time and effort estimates are central pillars of the Agile framework most commonly used to execute IT projects: Scrum (Schwaber & Sutherland, 2017). To generate accurate, useful estimates, it is essential that the estimator understand the purpose of an estimate and the importance of having proper information and an appropriate level of experience.

Although the concept of estimation and the various estimating approaches are quite easy to understand, generating credible and accurate estimates, especially in IT projects, can be very challenging, because of contextual reasons, such as lack of proper information, lack of adequate training or lack of proper predisposition (Nelson & Morris, 2014). To develop and improve estimation competencies, several estimation specialists favour estimation calibration exercises, that is, a practice environment where learners can evaluate and rectify their estimates while ascertaining their estimating competencies (e.g., Hubbard, 2014; Nelson & Morris, 2014; Woo, 2018). Through estimation calibration exercises, learners become aware of the quality of their estimates and can readjust throughout the exercises to calibrate their own estimation competencies (Hubbard, 2014). Simulation-based training possesses many characteristics that overlap with estimation calibration exercises and thus can potentially support the development of estimation competencies.

2.2. Simulation-based training

Simulation-based training (SBT) is "any synthetic practice environment that is created in order to impart competencies (i.e., attitudes, concepts, knowledge, rules or skills) that will improve a trainee's performance" (Salas, Wildman, & Piccolo, 2009, p. 560). This active learning technique tries to reproduce real-life situations via a simulation, an artificial environment created to manage an individual's or a team's experiences with reality (Salas, Wildman, *et al.*, 2009). Several scholars have emphasized that active learning techniques such as SBTs stimulate participants' motivation; favour team development; create realistic, stimulating, manageable, safe and risk-free environments; bring classrooms closer to "real-life" situations; and, when compared to "traditional" techniques, accelerate knowledge integration and recall (D. A. Kolb, 2014; Salas, Wildman, *et al.*, 2009; Tiwari, Nafees, & Krishnan, 2014).

Given that learning estimation competencies is central to the proposed PE-SBT, and that different definitions and conceptualizations of competency exist (e.g., Gómez, Aranda, & Santos, 2017), it essential to define what is meant by competency. Following Gomez *et al.* (2017), competency is defined here as "a composite of the knowledge, skills and attitudes required to adequately undertake a task or intellectual process that is appropriate to a professional performance in a defined context" (p. 2198).

The PE-SBT developed and tested in this study seeks to replicate the challenges faced by IT project members, analysts or managers, when faced with a need to estimate, while simultaneously educating the students about the job of estimating in IT projects (Weekley, Hawkes, Guenole, & Ployhart, 2015). In terms of learning competencies, the students should learn, through the PE-SBT, estimation-related knowledge, skills and attitudes as they undertake two estimating tasks in a defined context simulating an IT project (Gómez *et al.*, 2017). Throughout the PE-SBT, students play different roles; evaluate and analyse information, objectives and constraints; make decisions; and take actions; all while having fun.

2.3. Play at work

Play[5] is attracting increasing interest among today's managers as their organizations are – more than ever before – pressured to increase their productivity

[5] In this study, we focus on adult play as opposed to child play (Petelczyc *et al.*, 2018).

and innovate, while their environments are becoming more complex and uncertain (Bateson, 2015; Petelczyc, Capezio, Wang, Restubog, & Aquino, 2018; Reeves, Fuller, & Gutiérrez-López, 2018). Over the years, several definitions of adult play have been proposed, in both the practitioner and academic literature, creating some confusion regarding what the phenomenon is and how to interpret the research findings on play at work (Petelczyc *et al.*, 2018).

Van Vleet and Feeny (2015) provide an overarching definition of play that encompasses the key elements of the play definitions identified in past studies. They define play as "an activity that is carried out for the purpose of amusement and fun [1], that is approached with an enthusiastic and in-the-moment attitude [2], and that is highly interactive [3]" (p. 631). The notions of amusement (i.e., a condition of pleasure) and fun (i.e., a mood of enjoyment) underscore and explain why, when adults play, they are process-focused. This process focus explains why adults usually have a higher-order end goal in mind when they play, such as increasing their productivity or learning new skills (Van Vleet & Feeney, 2015). The enthusiastic, in-the-moment attitude characterizing play allows participants to take some psychological distance from external responsibilities and stressors, which helps them become highly involved and in the flow (Csikszentmihalyi, 2008; Petelczyc *et al.*, 2018). The state of flow can help participants increase their subject matter learning, competency development and satisfaction. Finally, the highly interactive nature of play means that playful activity can increase bonding and social interactions between individuals as well as providing them with feedback from which they can learn (Argyris, 2002; A. Y. Kolb & Kolb, 2010).

Many researchers have shown that play can positively impact individual-level variables in both working and learning contexts, such as job satisfaction (+), stress (–), task involvement (+), creativity (+), etc. Play can also impact team- and relational-level variables, such as trust (+), creative climate in meetings (+), bounding and social interactions (+), etc. Finally, play can influence organizational-level variables, such as flexible organizational decision-making (+), organizational creativity (+), etc. (Bateson, 2015; Sørensen & Spoelstra, 2011; Webster & Martocchio, 1993). Looking more specifically at studies that have focused on play and learning, the results show that play increases training transfers, interest in tasks, engagement, motivation, mastery, sense of competence and, ultimately, learning (A. Y. Kolb & Kolb, 2010; Petelczyc *et al.*, 2018; Webster & Martocchio, 1993)

In the practitioner literature, Reeves *et al.* (2018) provided a complementary perspective to Van Vleet and Feeney's (2015) definition of play by defining it, in an organizational context, as "deploying improvisation and imagination, to inspire ourselves and others toward more effective exploration of possibilities" (p. 1). For Reeves *et al.* (2018), improvisation means that, during play, individuals must improvise since they have to respond quickly to unknown external stimuli by doing things quickly, with minimal preparation. Thus, in a play context, individuals can try out different possibilities, explore new avenues in a safe environment and learn by trial and error. Further, Reeves *et al.* (2018) noted that play itself is fun and is essential for people's long-term development since, through imaginative play, individuals develop a mind-set that helps them better envision positive and negative possible futures. Finally, play creates a space where inspiration can occur to favour engagement, idea sharing and learning.

Some scholars use the notion of "serious play" to refer to playful activities and innovative methods that draw on the imagination and integrate cognitive, social and emotional dimensions of experience to tackle problems or challenges which typically arise in work-related contexts. During serious play, participants should feel free to try and safe to make mistakes. Generally, there is no competition, no rules of engagement and no clear definition of success (Gauntlett, 2007; Roos, Victor, & Statler, 2004; Statler, Heracleous, & Jacobs, 2011). Serious play differs from the notions of gaming and "serious games", which usually involve a digital support (e.g., Allal-Cherif, Makhlouf, & Bajard, 2014; Cohard & Marciniak, 2015; Lépinard, 2014). For instance, Boughzala (2014) defines serious games as "video or computer games designed for training or educational purposes" (p. 2). Serious games are usually costly to develop and deploy; they require substantial resources; some level of competition is implied; the rules of engagement often depend on the strategy chosen; there is a clear definition of success; and there are clear rules and structures.

Although no instructions exist on how to create effective play contexts, Reeves *et al.* (2018) provide four guidelines on creating conditions that favour effective play: (1) *derisk play:* reduce the negative consequences or outcomes of actions during play and create a psychologically safe context; (2) *suspend objectives:* eliminate goals and assessments; (3) *create special play zones:* since play is set apart from "normal" activities, use physical settings or objects to create a clearly delimited play space so participants who enter in the space adopt a playful mind-set; and (4) *play is unclear:* since progression is usually unclear in play (so that participants wander around and make connections by themselves, favouring learning), it is essential to inform participants that this lack of clarity is normal when playing and that they should feel free to try things out.

One tool that can (1) afford the development of an SBT; (2) reflect the behaviours and cognitive operations used by IT project estimators; (3) provide a safe space to foster deeper learning; and (4) favour effective play is LEGO® bricks (Reeves *et al.*, 2018; Weekley *et al.*, 2015).

2.4. LEGO® bricks: A tool for immersion in "real-life" situations

Developing an effective SBT can be challenging since it must recreate an understandable real-life situation, accommodate different learning styles, and let students retain some control over their learning; moreover, SBTs are usually costly and time-consuming (Bell, Kanar, & Kozlowski, 2008; Salas, Rosen, Held, & Weissmuller, 2009). One key decision when developing SBTs is to identify the types of tasks performed by students and the tool used so that they can rapidly immerse themselves in an experiential learning mode (D. A. Kolb, 2014). Thus, to recreate an immersive "real-life" situation where students can develop their project estimation competencies, LEGO® bricks were used since most students have played with such bricks in childhood. Even though such bricks are usually associated with children's learning activities, they are being used more widely in adult learning activities since they constitute a practical tool for reflecting, discussing and learning (Steghöfer, Burden, Alahyari, & Haneberg, 2017; Taylor & Statler, 2014).

Creating LEGO® models requires little preparation or planning and is fast, as the bricks can easily be interconnected in numerous and unexpected ways, even with little skill (Gauntlett, 2007). In addition, LEGO® bricks are characterized by low floor, high ceiling and wide walls because it is easy for less experienced students to get started (i.e., low floor); construction becomes progressively more complex and sophisticated models can be built (i.e., high ceiling); and students' imagination can take a project in countless directions (i.e., wide walls) (Resnick & Silverman, 2005).

LEGO® bricks were used in the PE-SBT because they allow one to rapidly create an affordable and flexible experiential learning environment where students can apply concepts or skills they have learned, learn new ones, and reflect on their decisions and actions. Experiential learning is a particular form of learning from life experience, often distinguished from classroom learning and lectures (D. A. Kolb, 2014). The PE-SBT tried to recreate a "real-life" estimating situation with LEGO® bricks where the hands-on, practical situation experienced by students served as a springboard to reflect, discuss and learn about IT project estimation (Nelson & Morris, 2014; Schwaber & Sutherland, 2017). By manipulating bricks, students become immersed in an active state that stimulates various learning modes and allows them to go through Kolb's (2014) full learning cycle: active experimentation, concrete experience, reflective observation and abstract conceptualization. Thus, the PE-SBT allows students to encounter two elements often missing from traditional classroom settings: active experimentation and concrete experience (A. Y. Kolb & Kolb, 2005).

LEGO® bricks were also used because, when individuals manipulate these bricks, they activate brain regions that help to anchor knowledge and skills in a deeper, more meaningful way. This result follows from the "hands-on, minds-on" connections stimulated by LEGO® bricks (Kristiansen & Rasmussen, 2014). In addition, by working with LEGO® bricks, individuals create and recreate their own knowledge because this action stimulates the formation of connections between new and existing knowledge (Papert, 1993). Finally, LEGO® bricks were used in the PE-SBT because of their playful aspect which, in a learning context, can increase students' engagement, stimulate curiosity and motivation, reduce habits and prejudices and, ultimately, help them develop new competencies (A. Y. Kolb & Kolb, 2010; Webster & Martocchio, 1993). The PE-SBT presented here is part of the "serious play" movement, which promotes active learning, innovation and creativity (e.g., James & Nerantzi, 2019; Roos *et al.*, 2004; Statler *et al.*, 2011).

3. OVERVIEW OF THE LEGO® PROJECT ESTIMATION SIMULATION-BASED TRAINING

The LEGO® project estimation (PE) simulation-based training (SBT) was developed to stimulate students' learning and reflection on IT project estimation. During the PE-SBT, students experiment with the factors that influence the estimation process in a situation where the project scope is clear: they have to estimate the time and effort needed to build a transport vehicle (a LEGO® model), based on different levels of information and required experience. The transport vehicle is used as a metaphor to represent an IT project (Lakoff & Johnson, 2003). The LEGO® bricks represent the resources needed to develop a particular IT and the various levels of information and experience parallel the level of uncertainty, the clarity of clients' needs and team members' experience (Nelson & Morris, 2014; Schwaber & Sutherland, 2017). Thus, after participating in this SBT, students should be able to:

1) Understand the importance of having clear, accurate, comprehensive and detailed information on the client's requirements and deliverables as well as on the project's context and constraints so they can establish accurate estimates.

2) Grasp the role experience plays in establishing project estimates.

3) Understand the complementarity of top-down and bottom-up estimation techniques.

3.1. Description and phases of PE-SBT

During the PE-SBT, students must work in teams to estimate the effort needed to build a LEGO® model.[6] Table 1 presents the sequence of activities the students go through, along with their estimated duration. Activities #1 to #4 are the preparation activities required to set up the simulation, whereas activities #5 to #10 are the estimating and building activities – the core of the simulation.

Table 1: Project estimation SBT phases and time

Activities & Time	Activity descriptions
Preparation activities	
1 – Introduction to Project Estimation SBT (3 min.)	– Introduce the pedagogical activity on IT project estimation. – Present the simulation context and instructions and criteria. – Establish parallels between the PE-SBT and real-life IT projects.
2 – Team Creation (5 min.)	– Ideally, a minimum of 3 teams is needed for the simulation so the 3 building situations, each with different levels of data richness, can be compared: textual description, image (box) and building instructions (see forms 1 and 2 for details).
3 – Distribution of Vehicle and Building Situations (4 min.)	– Teams draw labels to identify vehicle and building situations. – Distribute the textual descriptions of vehicles to the appropriate teams.
4 – Simulation Phase (3 min.)	– Present the main phases to students: estimation and building phase, team presentation phase, and group debriefing and feedback phase.
Estimation and building activities	
5 – Initial Estimation Phase (10 min.)	– 10 minutes to estimate the time needed to build their LEGO® models (see form 1 – Appendix A). – Teams are instructed first to estimate individually and then to estimate collaboratively. – Teams with textual descriptions should leave the classroom so that they cannot see the images or instructions the other teams receive. – Distribute boxes and building instructions to the appropriate teams.
6 – Building Phase – Part 1 (8 min.)	– Have teams with textual descriptions return to the classroom. – Distribute LEGO® sets to every team. – Remind teams to start the timer once they start building (see Figure 1).
7 – Estimate Revision Phase (5 min.)	– Six minutes after the beginning of the building phase, ask all the participants to stop building, stop the timers and revise their initial estimates (see form 1 – Appendix A).

[6] See Appendices A and B for details on the simulation's requirements, context, instructions and phases, as well as for the detailed plan and the pedagogical material needed.

8 – Building Phase – Part 2 (15–30 min.)	– Give the signal to continue building. – Once the models are built, collect three times from each team: initial estimate, revised estimate and actual time.
9 – Model Presentations and Observation Sharing (20 min.)	– One member of each team presents their vehicle to the rest of the class. – The instructor evaluates the extent to which vehicles do (10) or do not (1) meet the client's needs/requirements, on a scale from 1 to 10. – Each team's observer is asked to share his/her observations.
10 – Post-Simulation Debriefing and Discussion (20 min.)	– The following questions can be asked to initiate discussion, stimulate exchanges and foster learning: What approach did you take to make your estimates? On what basis? What estimation technique(s) were used? What elements were used to make accurate estimates? What have you learned? Etc. – Each of the observers shares their observations with the rest of the group on (1) Estimation techniques used; (2) Building strategies; (3) Team dynamics; (4) Significant events and their management; and (5) Difficulties encountered and their management. – Various techniques and recommendations should be used to increase the effectiveness of the debriefing activity (e.g., Allen, Reiter-Palmon, Crowe, & Scott, 2018; Kolbe, Grande, & Spahn, 2015)

Figure 1: Students at work on the simulation

Estimation Phase

Building Phase

Before building their model (Activity 6 in Table 1), each team must develop an estimate of the necessary effort, namely time and tasks, based on the information provided to them during the initial estimation phase (Activity 5). Each team is randomly assigned to one of three estimation situations: (1) textual description only, (2) picture on the LEGO® box, or (3) detailed building instructions provided by LEGO®. Each situation provides different levels of information quality, quantity, precision and richness. For instance, textual descriptions of LEGO® models describe the length, height and width of the models, the various parts, and distribution of the LEGO® bricks by colour; no images or building steps are given to students. Conversely, the building instructions provide a rich, precise and detailed step-by-step description, with images and descriptions of the bricks needed at each step.

For the initial estimation phase (Activity 5), students are instructed to, first, make individual estimates of the tasks required to build the model and the time needed to complete those tasks. Once the individual estimates have been completed, teams must collaboratively establish their final estimates. To do so, the students have to discuss the issue, developing a shared understanding and forcing them to question and readjust their own initial estimates. Furthermore, in the process, students will learn that collective knowledge or the "wisdom of the crowd" (Kao *et al.*, 2018) is usually more powerful than individual estimates.

Following the initial building phase (Activity 6), students are allowed to reflect on their initial estimates and revise them based on the experience and the new information (e.g., number, sizes and types of bricks) they have gained while building during Activity 6. Throughout the building phases, students gain experience with building their LEGO® model – experience with the number, sizes, types and colours of the LEGO® pieces – just as team members gain experience with a technology while developing it during an IT project. Also, as would be the case in a real IT project, students gain experience with team dynamics, such as the distribution of roles and responsibilities, how to do the taskwork (e.g., build the vehicle components separately or build the vehicle as a whole), how to organize work (e.g., separate pieces by colour, type or size), how to manage conflicts, etc.

Further, the estimate revision phase (Activity 7) and the debriefing and discussion phase (Activity 10) allow students to adjust their mental models and fine-tune their decision-making rules (Tiwari *et al.*, 2014). In the PE-SBT, such phases are planned to allow students to engage in double-loop learning (Argyris, 2002). Globally, by receiving different levels of information quality and richness and readjusting their estimates after executing some building tasks, students are able to reflect on the challenges, difficulties and key elements of project estimation and develop their estimation competencies.

Relatively simple LEGO® sets are needed to conduct the PE-SBT. In our SBT, we used three different LEGO® sets[7] representing three kinds of transport vehicles (see Figure 2). Three sets were used because we wanted to create some diversity as the PE-SBT was deployed with groups of 20 to 50 students. This was useful during the debriefing and discussion as it highlighted the effects of diversity, that is, different models, on the estimating and building challenges faced by the students.

Figure 2: Pictures of the three LEGO® models used

[7] These LEGO® sets can be replaced by other sets with a similar number of pieces, to conduct this PE-SBT.

4. METHODOLOGY

The PE-SBT was conducted with 123 undergraduate students who were enrolled in the "IT Project Management" course at a North American university. It took place over four semesters. The simulations were held in a regular classroom and students worked around tables arranged in islands (see Figure 1). The students were divided into teams of three or four. During the simulation, the main incentive for the students was to be able to experiment with and reflect on the concepts and estimation tools they had read about in their preparatory readings. Unlike a "serious game", there is no winning team and no participation points are awarded during the simulation since the emphasis is on learning rather than competing. However, a few questions on the final exam relate to concepts related to estimation. In addition, the simulation's results are neither noted nor evaluated directly. We told students very clearly and repeatedly that this simulation was not a competition, but rather a learning experiment where they could experiment, reflect on and discuss the challenges and tools used in IT project estimates.

The simulation was carried out in class, during normal class hours. In addition, we made it clear to students that this simulation would allow them to develop their estimation competencies in addition to applying and concretely experimenting with concepts and tools about which they had previously read. We had a participation rate of 100%. Regarding operating rules, we presented the general framework of the simulation (see Table 1) without giving students strict, rigid rules. The goal was to allow students to adapt and try out various strategies when they encountered certain challenges or difficulties related to estimation. During the debriefing session, the different strategies the students used to overcome challenges and difficulties were presented and discussed with the whole class.

The simulation was pre-tested with students from two other groups to adjust the SBT phases, the instructions and the LEGO® models used. To assess the extent to which the PE-SBT was meaningful, evocative and relevant for students and provided a realistic representation of "real-world" estimation situations, observations and questionnaires were used to collect data. A questionnaire[8] was developed using existing measures to evaluate the students' experiential learning perception (Clem, Mennicke, & Beasley, 2014), the quality of their team experience (McCreery, 2003), team dynamics and students' satisfaction level (Barki & Hartwick, 2001). Four open-ended questions were also included in the questionnaire, which the students completed right after the workshop.

For each of the four PE-SBT sessions, two of the authors were present in the classroom. One played the instructor role, that is, prepared and presented the PE-SBT, gave the instructions and answered students' questions, led the debriefing and discussion session, etc. The other author played the observer role during the PE-SBT: walked throughout the classroom during the simulation without intervening or commenting; noted down observations using the educational validity framework (Stainton, Johnson, & Borodzicz, 2010); conducted post-activity interviews with students, etc.

For the observations, Stainton *et al.*'s (2010) educational validity framework was used as a guideline. According to these

[8] The questionnaire items are presented in Appendix C.

authors, a simulation's educational validity depends on the quality of its design and implementation and should be evaluated along three key dimensions:

1) **Representation**, or the extent to which the simulation "provides a realistic representation of the real-world business environment" (Stainton *et al.*, 2010, p. 717), is sufficiently challenging and complex without being confusing, and is stimulating enough that students are motivated by their tasks.

2) **Content**, or the extent to which the simulation is general enough to stimulate motivation, integrate double-loop learning (Argyris, 2002), and allow students to expand their knowledge and learning; and

3) **Implementation**, or the extent to which the simulation allows students to apply their knowledge to enhance their cognitive processes, links the decisions made by students to their performance, supports "learning by doing", is affectively rewarding and enjoyable, and is experiential so students can reflect on what they learned.

5. RESULTS AND ANALYSIS

In this section, we report on the quantitative and the qualitative data collected during and after the LEGO® PE-SBT. We also present an analysis of these results.

5.1. Quantitative data: Results and analysis

First, in the questionnaire, we used Clem *et al.*'s (2014) self-report instrument developed to measure students' perceptions of the "meaning or value of experience-based instruction" (Clem *et al.*, 2014, p. 493). This instrument has 28 items, grouped into four scales; each scale can be scored by averaging the answers to the individual items and can be interpreted separately. A 7-point Likert scale where 1 = Strongly Disagree and 7 = Strongly Agree was used. The **authenticity** subscale, which refers to the way information is provided to students, had a mean score of 5.07; **active learning**, which refers to students' engagement with the learning material, had a mean score of 5.56; **relevance**, which refers to the internalization of and reflection on students' experiences to connect new and old knowledge, had a mean score of 5.16; and **utility**, which refers to the connections students make between their experience and future opportunities, had a mean score of 5.22.

Table 2: Descriptive statistics

Scales	Mean	Median	Var.	S.D.	Min.	Max.
Value of experience-based instruction scale (Clem *et al.*, 2014)						
Authenticity	5.07	5	0.93	0.97	2.2	7
Active learning	5.56	5.57	0.68	0.82	3.14	7
Relevance	5.16	5.22	0.77	0.88	2.67	7
Utility	5.22	5.14	0.68	0.82	2.85	7
Quality of the team experience (McCreery, 2003)	6.30	6.33	0.67	0.82	2.22	7
Satisfaction with teamwork (Barki & Hartwick, 2001)	4.28	4.5	0.46	0.68	2.25	5

These results show that students' perception of the experience-based PE-SBT is very favourable. The results highlight the learning potential of the PE-SBT as it can enhance students' learning process by increasing their motivation, their preparedness, their confidence and their understanding of IT project estimation. Table 2 provides the descriptive statistics for the scales used in the questionnaire.

In addition, to assess the quality of the team experience, McCreery's (2003) nine-item scale was used. A composite score was calculated by averaging the scores of the individual items. The mean composite score was 6.30 on a 7-point Likert scale where 1 = Strongly Disagree and 7 = Strongly Agree. Three items – Team members cooperated well through the exercise (6.77), Our team maintained a pleasant working atmosphere (6.74), and Overall, I am satisfied with my team experience (6.54) – had scores over 6.5, whereas three items –The workload was fairly balanced across all team members (5.80), Team members all participated equally in the team decision-making process (5.74), and Team members were highly motivated to perform well in the exercise (5.91) – were scored just below 6. For satisfaction with teamwork (Barki & Hartwick, 2001), the mean composite score was 4.28 on an 11-point scale where –5 = Very Unsatisfied and 5 = Very Satisfied.

5.2. Qualitative data: Results and analysis of open-ended questions

The questionnaire also had four open-ended questions, which focused, from the students' perspective, on the advantages and disadvantages of the PE-SBT, their satisfaction level and the key elements learned.

Concerning **advantages**, students seem to have appreciated the fact that, through the PE-SBT, they were able to put into practice what they had learned theoretically or, as one student put it "to learn the theory concretely." In the same vein, another student mentioned that the PE-SBT "gives us project estimation experience and allows us to put the theoretical techniques of estimation into practice." Other students also highlighted the fact that the PE-SBT was practical and related to a real challenge faced by project team members. For several of them, estimating became more concrete and tangible, which should increase their retention and help them better develop their estimation competencies. Students mentioned that the PE-SBT allowed them to "better understand and retain the material seen in class" as well as to have a "real, tangible and practical learning experience." Finally, students seem to have really appreciated the double-loop learning process (Argyris, 2002) implemented in the PE-SBT via the estimate revision phase (Activity 7) and the post-simulation debriefing and discussion (Activity 10). As one student said: "We really appreciated the fact that we could periodically review our estimates and adjust them, as well as our mind-set, as new information became available." Thus, much as in estimation calibration exercises (Hubbard, 2014), students who experienced the PE-SBT had the possibility to evaluate and rectify their estimates while assessing their own estimating competencies.

As for **disadvantages**, some students seem to have had a hard time estimating with the textual descriptions. Indeed, one student mentioned that "we didn't have time, since we had the textual description," while another said, "without an image or plan, it was hard to estimate the exact time." However, since one of the objectives was to increase the students' awareness of and sensitivity to the importance of quality information and experience in estimating, we can say that this goal was achieved. Indeed, students did not simply understand the disadvantages of incomplete, inaccurate and poor information, they experienced them and felt the emotions associated with this kind of situation. Thus, their learning should be more profound and their competence at estimation improved. Other students did not have the impression of learning but only of playing: "I had the impression of playing, not learning. But it was fun anyway." As mentioned previously, individuals can learn a lot through play without feeling as though they are learning. Finally, other students felt uncomfortable during the PE-SBT since they were not used to learning in a playful mode and simulation-based context: "I am more theoretical, so learning this way is challenging for me." Despite these discomforts, all the students completed the simulation, and learning can certainly arise from such discomforts.

Regarding the students' **satisfaction level**, several students highlighted the fact that they had a great time and that learning through the PE-SBT was more fun than "traditional" approaches: "It allowed us to have fun while learning relevant notions" or "It's more fun to learn like this than just listening in class." Some students emphasized that, in terms of retention, they would definitely remember what they learned during the PE-SBT: "It will remain in our memory." Finally, other students pointed out the dynamic, playful aspects of the PE-SBT, which seem to have facilitated their learning and helped them better develop their estimation competencies: "It was entertaining and it's different from a lecture. I like interacting with people, managing and practicing what I learn, and I did all these things" or "It's playful; it prevents you from getting lost while understanding the challenge of estimating."

Finally, in terms of the **key elements learned**, most students emphasized that "the more information you have (text, images, plan), the better the result" and that "having specific instructions and information can help us make better estimates". Such remarks provide support for the research objectives, which were to increase students' awareness of the central role played by information in estimating and help them develop their estimation competencies via an alternative pedagogical approach which combined the affordances and advantages of simulation-based training and LEGO®. Several students also realized that, as they accumulated new information during the building phases and gained experience with the tasks, their previous estimates had to be readjusted in the light of this new information and experience, to increase the accuracy of their estimates: "Time estimates must be continuously adjusted" or "Time is underestimated and initial estimates often require adjustments. It was nice to have time to revise our estimates." Finally, some students recognized the central role played by the exchange of information in developing collective knowledge, which should help generate more accurate estimates (Kao *et al.*, 2018): "Communicating and exchanging viewpoints is essential for estimating."

5.3. Qualitative data: Results and analysis of observations

Finally, based on our observations during the four simulations and quotations gathered during the post-simulation debriefing and discussion (see Table 1), the data show that PE-SBT is educationally valid: it covers the content and implementation dimensions of Stainton *et al.*'s (2010) educational validity framework well and the representation dimension relatively well.

Regarding the **content dimension** (Stainton *et al.*, 2010), students were motivated by the PE-SBT; as one student said, "We could feel the excitement in the air." Most of them did not merely participate but were actively involved in the simulation. They continually encouraged each other and remembered that they had to work fast and respect their estimates. Furthermore, students really appreciated the estimate revision phase since it allowed them to reflect on their initial estimate and readjust it on the basis of the experience and new information they had gained from the first building phase. As one student said, "Luckily, we were able to readjust because our initial estimate was completely off the mark."

The debriefing and discussion phase allowed students to compare different estimation techniques. It provided an opportunity for students to reinforce what worked, identify difficulties, self-correct and transfer those learnings to help improve subsequent tasks. Most of the teams given textual descriptions relied either on their intuition, on guessing or on consensus for their estimates. Teams with images of the LEGO® models mainly used analogical approaches to prepare their estimates as several team members had played with LEGO® in the past and could compare the task with previous models they had built. Finally, the teams with the building instructions mostly used functional point methods to create their estimates as they multiplied the average time to complete one step by the number of total steps to build the LEGO® model. The estimation approaches used by the students varied based on the quality and richness of information they were given – text vs. images vs. building instructions – and provided an opportunity to engage in active experimentation and concrete experience of estimation approaches (D. A. Kolb, 2014).

Like the Sprint Retrospective in Scrum, which allows an IT project team to inspect itself and identify areas for improvement (Schwaber & Sutherland, 2017), the PE-SBT's debriefing and discussion phase allows students to fully engage in their learning by favouring reflection and thinking (A. Y. Kolb & Kolb, 2010). Students also reflected on and discussed the importance of having rich, relevant information as well as expertise and experience to generate accurate estimates. For instance, in one of the teams, none of the members had ever played with LEGO® in their lives; the result was that they had a really hard time estimating and building their model.

In terms of the **implementation dimension** (Stainton *et al.*, 2010), the PE-SBT seems to support students in applying their knowledge to enhance their cognitive processes, adjust their mental models and develop their estimation competencies. Before coming to class for the simulation, students had to read a book chapter on estimating (Larson & Gray, 2011). Once in the classroom, the session began with the simulation and the theory was covered afterward. As we walked among the various teams in the classroom, we observed several teams referring to the concepts and estimation methods they had read about before coming to class and trying to apply them. Moreover, during the debriefing and discussion phase, they reported that they had attempted to apply the concepts and methods they had read about but said that it was more challenging than they expected to use them in a "real-world" situation. As one student mentioned, "Estimation techniques are easy to understand when you read about them. However, applying and using them in real life, even with LEGOs, it's a different story. You realize that it is way more difficult and challenging than expected."

Based on the challenges encountered by students, the debriefing and discussion allowed them to explain and clarify the issues and difficulties associated with estimation concepts and methods and highlight the similarities between the PE-SBT and real IT projects. With the PE-SBT, students' learning about estimates became concrete as they were able to directly link the theoretical concepts to their experience during the simulation. The students seemed to be having a good time as they developed their estimation competencies through "learning by doing."

As for the **representation dimension** (Stainton *et al.*, 2010), the PE-SBT appears to provide a sufficiently challenging, competitive and complex environment for students. It was not confusing for most of them, although some of the students in the teams with textual descriptions showed signs of frustration. For some of those students, it seemed simply impossible to build a LEGO® model without images or instructions. This frustration stems from the fact that the information provided (i.e., the textual descriptions) to establish their estimates was not good quality, was inadequate and lacked precision and richness. Despite those frustrations, these students did not merely understand but experienced the importance of having quality information to establish accurate estimates. This kind of frustration can also be experienced in real IT projects when estimators do not have access to quality data (Nelson & Morris, 2014).

6. DISCUSSION

The results presented in this paper support the educational validity of the LEGO® PE-SBT (Stainton *et al.*, 2010) and show that LEGO® bricks, combined with simulation-based training, can help students learn, hands on, about IT project estimation and develop their competencies (Nelson & Morris, 2014). First, as presented in section 5, students who participated in this SBT reported that their learning experience was intense, engaging, pleasant and memorable (Salas, Wildman, *et al.*, 2009; Tiwari *et al.*, 2014). The questionnaire results also show that the students enjoyed an authentic, engaging, relevant and useful experience (Clem *et al.*, 2014).

Indeed, Clem's *et al.* (2014) Experiential Learning Survey measured the "students' perception of value of an experiential learning activity" (Clem *et al.*, 2014, p. 503) using four dimensions: authenticity, active learning, relevance and utility. As shown in section 5.1, the scores on the four dimensions were positive ranging from 5.07 to 5.56 on a 7-point scale. In terms of active learning (5.56), the results indicate that students were stimulated by what they were learning, that they were emotionally engaged and that the PE-SBT was sufficiently challenging enough to put them in a flow state (Csikszentmihalyi, 2008). Moreover, the students seem to have found the PE-SBT relevant (5.16), meaning that it made sense to them, they could identify with the learning experience and that cared about what they had learned. Regarding authenticity (5.07) and utility (5.22), the positive results mean that students felt that the learning experience they had with the PE-SBT helped them better understand the challenges associated with estimating in IT projects, it would help them in the future and they saw value in this learning experience. In short, the positive results show the relevance and usefulness of such a simulation in order to gain hands-on experience with IT project estimation. On the other hand, although positive, the results remain modest and leave room for improvement.

Through the PE-SBT, students also felt that they had learned meaningful and useful aspects of estimating, such as the importance of having rich, relevant information, the key role of expertise and experience when estimating, and the differences between the various estimation methods (Larson & Gray, 2011). They also learned about team dynamics in the context of project estimation, such as the importance of listening, collaborating, sharing, validating, adjusting, focusing and adapting (McCreery, 2003). Thus, with this PE-SBT, the students engaged in two key activities that are often missing in the traditional classroom setting: active experimentation and concrete experience (A. Y. Kolb & Kolb, 2005; D. A. Kolb, 2014).

Bell *et al.* (2008) argued that, to develop effective experiential learning environments, the instructional features of an SBT should be evaluated along four dimensions: content, immersion, interactivity and communication. In terms of content and communication, the PE-SBT's instructional features are relatively rich since they are provided in various formats (e.g., paper, images, instructor, etc.) and offer two-way, synchronous communication between all participants. This context enables the instructor to evaluate students' progress in real time and provide real-time guidance. As for interactivity, the PE-SBT's instructional features are rich as students can interact with each other and with the instructor. These frequent interactions throughout the exercise can be motivating and help students to learn by exchanging feedback with other individuals. Finally, the PE-SBT provides students with an environment simulating "real-world" projects that prompts the essential underlying psychological processes relevant to IT project estimation.

The LEGO® PE-SBT presented here should help students learn and become aware of the opportunities and challenges associated with IT project estimation. It is aligned with Whetten's (2007) call to develop more "learning-centred" course activities in which students' learning objectives are focused on remembering, understanding, applying and analysing. When we look at the students' comments and the questionnaire results, those four learning objectives seems to have been achieved here. Moreover, the use of LEGO® bricks allows students to immerse themselves in "real-world" projects; the bricks serve as a metaphor to represent reality (Morgan, 2006). One challenge faced by instructors is getting students to appropriate and internalize both theoretical and practical estimating concepts. The students who participated in the PE-SBT mentioned that using LEGO® bricks helped them anchor theoretical concepts and facilitated the development of their estimation competencies which, otherwise, might have been too theoretical and abstract for them.

Also, as Taylor and Statler (2014) argued, the intrinsic physical properties of LEGO® bricks – the affordances provided by these properties – combined with the key characteristics of SBT, can positively affect students' engagement levels and learning processes. Indeed, when students are emotionally engaged in what they are doing, they learn more effectively (Taylor & Statler, 2014). The study's results seem to support Taylor and Statler's argument since the students' level of engagement and learning experiences were high and positive. Thus, these results show that the pedagogical approach developed and tested here – combining an active learning technique, SBT, with LEGO® bricks – can support students in developing their estimation competencies and help them increase their awareness of the importance of quality information and experience in estimating.

IT managers should be pleased with the results obtained and the observations made in this study since the students who participated in the PE-SBT seemed to be more sensitive to and aware of the challenges and good practices related to estimation in IT projects (Nelson & Morris, 2014). Indeed, the students seem to have understood the central role of information quality and the importance of experience in formulating accurate estimates. In the context of IT projects, accurate estimates should make it possible to reduce the risks, make better decisions, improve planning, facilitate monitoring, support the selection and evaluation of projects and ultimately improve the management of IT projects (Tanveer *et al.*, 2017; Trendowicz & Jeffery, 2014). Moreover, given that estimates have become a central pillar of most Agile methodologies and since these methodologies are increasingly used in IT projects (Dybå & Dingsøyr, 2008; Schwaber & Sutherland, 2017), it is good news for IT managers that a simulation to develop estimation skills now exists. Finally, sound and accurate estimation, used effectively throughout a project's lifetime, should have a positive impact on project success (Standish Group, 2016).

6.1. Limitations and research avenues

This study has certain limitations that should be acknowledged. First, due to its simplicity and its limited scope, the PE-SBT does not reflect all the stakes affecting real, complex IT projects. However, it does reflect the uncertainty, interactions, incomplete information, interdependencies and collaborative nature of real-world IT projects (Chua, Lim, Soh, & Kien Sia, 2012). In addition, the LEGO® process developed within the PE-SBT is artificial in its time scale, which does not reflect the long-term temporal character of real IT projects. However, it provides a useful context for novice estimators to develop their estimation competencies.

Moreover, the questionnaire was distributed and completed by the students at the end of the simulation. Thus, there is a possibility that students over-reported desirable attributes and under-reported socially undesirable ones. Several techniques were used to minimize social desirability bias (Nederhof, 1985), such as phrasing questions to show that it is acceptable to answer in a way that is not socially desirable, asking indirect or neutral questions, and having a self-administered questionnaire. Indeed, students were clearly informed that the questionnaire was anonymous, they had no obligation to answer the questions and the questionnaire would have no effect on their grades. In addition, the questionnaire was distributed and collected by one of the students who volunteered to do so. During this period, both the instructor and the observer left the classroom to let students complete their questionnaires with a minimum of influence from their social environment.

In a future study, it would be interesting to measure students' estimation competencies before and after the PE-SBT to capture the improvements triggered by the simulation. Another possibility would be to compare different groups, some using the PE-SBT and others learning estimation via more traditional approaches, such as lectures and paper-based individual exercises. Finally, the quantitative data collected could be used to develop a research model and research hypotheses.

7. CONCLUSION

This paper's objective was to contribute to the conversation about the challenges and opportunities related to teaching and learning IT project estimation in the classroom and present a pedagogical approach that can be deployed to help novices develop their estimation competencies. It gives teachers and instructors a clear example of a pedagogical activity that can stimulate students' learning and reflection regarding IT project estimation (Nelson & Morris, 2014). A simulation-based training (SBT), using LEGO® bricks, was developed and tested. Students who participated in the project estimation SBT sessions explored and applied various strategies for estimating and demystified estimation theories. They also understood and experienced the importance of information quality and richness and the key role of expertise and experience when making estimates. The results show that students had a positive learning experience. In terms of educational validity, the simulation provides a realistic representation of a real-world business environment where students can develop their estimation competencies and know-how through learning by doing. This project estimation SBT should allow students to realize that successful estimating is a happy mix of quality, precision and rich information with the right amount of experience!

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APPENDIX A: TEACHING NOTES – FOR INSTRUCTOR

OVERVIEW

This simulation-based training (SBT) program was developed to sensitize and introduce students to the challenges associated with estimating in the context of information technology (IT) projects. In this simulation, students must estimate the building time and efforts needed to assemble a LEGO® transport vehicle, that is, an existing LEGO® model, in three different building situations: (1) with the building instructions, (2) with an image of the vehicle, and (3) with a textual description of the vehicle.

During the simulation, students first prepare, individually and then in teams, estimates of the building time and the steps needed to complete the assembly of their LEGO® model without having seen the LEGO® pieces but using either (1) the building instructions, (2) an image or (3) a textual description of their model. Later, once they have started the construction of their vehicles and have gained some experience with the LEGO® pieces and with their teammates, the students are called upon to revise their building time estimates during the construction phase.

Once every team has completed the construction of their vehicle (their LEGO® model) and has noted (1) their first estimate, (2) their revised estimate and (3) the actual time needed to complete the construction, these three times will be compared and used during the post-simulation debriefing and discussion phase to make students aware of the importance of having high-quality, precise and rich information as well as experience when estimating.

PEDAGOGICAL OBJECTIVES

After participating in this project estimation SBT, students should be able to:

1) Understand the importance of having clear, accurate, comprehensive and detailed information on the client's requirements and deliverables as well as on the project's context and constraints to establish accurate estimates.

2) Grasp the role played by experience in establishing project estimates.

3) Understand the complementarity of top-down and bottom-up estimation techniques.

SIMULATION REQUIREMENTS AND DETAILED PLANNING – FOR INSTRUCTORS

This project estimation (PE) SBT is designed to help students become aware of and experience the challenges and difficulties associated with the estimation process in IT projects. During this PE-SBT, students will experience a situation similar to what happens in "real life" as they must make an estimate of the effort, in time and steps, needed to build their transport vehicle (LEGO® model) based on different levels of information quality, precision and richness: with the building instructions, with an image, or with a textual description.

Afterward, students will receive the LEGO® pieces to build their model. Throughout the building phase, students will gain some experience with building their LEGO® model, namely experience with the number, sizes, types and colours of LEGO® bricks. They will also gain experience with team dynamics, such as the distribution of roles and responsibilities, how to do the taskwork (e.g., build the vehicle components separately or build the vehicle as a whole), how to organize work (e.g., separate pieces by colour, type or size), how to manage conflicts, etc.

To conduct this PE-SBT, ideally a minimum of nine students is required. This number follows from the fact that each team needs a minimum of three students – two to build the LEGO® model and one to play the observer role – and that three different building situations – with the building instructions, with an image, and with a textual description – must apply to allow comparison and discussion during the post-simulation debriefing phase.

Furthermore, relatively simple[9] LEGO® sets are needed for this SBT. In our SBT, we used three different LEGO® sets representing three kinds of transport vehicles (see Figure 2).[10] Three sets were used because we wanted to create some diversity as the SBT was applied with groups of 20 to 50 students. This was useful during the post-simulation debriefing and discussion as it highlighted the effects of diversity on the estimating and building challenges faced by the various teams. In a situation where the number of teams is limited, for instance the minimum of three, all teams should use the same LEGO® set but with different building situations.

To conduct this PE-SBT, Table A1 presents a detailed plan of the simulation's phases and activities and the related time.

Table A1: Detailed plan for project estimation SBT

No.	SBT Activities	Time
Preparation activities		
1	***Introduction to Project Estimation SBT*** • Introduce the pedagogical activity on IT Project Estimation. • Present: a. Simulation context (see *Students' Section* for details (Appendix B); b. Simulation instruction and criteria; c. *Estimation Grid* (Form 1). • Establish parallels between the PE-SBT and real-life IT projects.	3 min.
2	***Team Creation*** • Each team should be composed of 4 students (minimum 3 per team): a. Minimum of 3 teams is needed to be able to compare the 3 building situations: textual description, image (box) and building instructions; b. Each student must play one of the three roles (see table A2); c. Present the three role descriptions; d. Distribute the *Estimation Grid* and *Observation Template* (Form 2); e. Explain the observation template.	5 min.

[9] If the LEGO® sets used are too simple (fewer than 75 pieces), the students will not find it very challenging to estimate their building time and assemble their models. If the models are too complicated (more than 200 pieces), the opposite situation will probably occur, and the simulation may take too long.

[10] Other LEGO® sets can be used. However, in that case, textual descriptions of the vehicles chosen (see Form 3) should be created to describe the models used in the simulation.

3	***Distribution of Vehicle and Building Situations*** • Each team must draw a label to identify which vehicle it must build and in which building situation (see Form 4 for labels): a. If you play with only three teams, make sure that all three teams build the same vehicle but with the three different building situations to allow for comparison at the end. • Distribute the textual descriptions of vehicles to the appropriate teams.	4 min.
4	***Simulation Phases*** • Present the main phases to students (see *Students' Section* for details): a. Estimation and building phase; b. Team presentation phase; c. Group debriefing and feedback phase.	3 min.
Estimation and building activities		
5	***Initial Estimation Phase*** • Each team will have 10 minutes to estimate the time needed to build their transportation vehicle: a. No indication of how to proceed for estimating should be given to students. Students will use various estimation strategies; for instance, some teams will provide a global estimate while others will list the main tasks and estimate each one separately. • Teams are instructed first to estimate individually and then to estimate collaboratively. • Distribute the textual descriptions of vehicles to the appropriate teams: a. Ask the teams with the textual descriptions to leave the classroom. Those teams must develop their estimates outside so that they cannot see the other teams' pictures (boxes) or building instructions. • Distribute the boxes and the building instructions to the appropriate teams so that they can use them to prepare their estimates.	10 min.
6	***Building Phase – Part 1*** • After 10 minutes, ask the teams with the textual descriptions to come back to class. • Distribute the LEGO® sets to every team and remind the observers to start the timer once the team starts building. • Each team will have 6 minutes for this Building Phase – Part 1. • Go around the class to collect each team's original estimate of the time to assemble their LEGO® vehicle. • Enter the various estimates in a spreadsheet that will be used in the debriefing phase (see Form 5 for an example).	8 min.
7	***Estimate Revision Phase*** • Six minutes after the beginning of the building phase, ask all the participants to stop building and stop the timers. • Now that the teams have seen the LEGO® bricks and have gained some experience building their vehicle and working with their teammates, ask each team to revise, first individually and then as a team, their initial estimates (See form 1 – Appendix A).	5 min.
8	***Building Phase – Part 2*** • Give the signal to the teams to continue building. • Collect the revised estimates and enter them in the spreadsheet. • As you see teams completing their vehicles, ask them how long it took to complete the LEGO® vehicle, then enter the final time in the spreadsheet.	15–30 min.

9	***Model Presentation and Observation Sharing Phase*** • After 30 minutes, most teams should have finished building their models; ask all the teams to stop building. • One member of each team presents their vehicle to the rest of the class; each team is given 1 minute max. • As the instructor, give each team a score from 1 to 10 to evaluate the extent to which their vehicle does or does not meet the client's needs. Enter the evaluation in the spreadsheet: a. 1 = Client's needs have not been met at all: the vehicle does not look like the original LEGO® model at all; b. 10 = Client's needs have been completely met: the vehicle looks exactly like the original LEGO® model; c. You can ask the rest of the students to approve (or disagree with) the evaluation. • Each team's observer is asked to share (2 minutes max.) his/her observations on: d. How was the estimation prepared? On what basis? What estimation technique(s) were used? e. What building strategies did the team use? f. Describe the team dynamics (e.g., conflict, coordination, communication); g. What significant events happened during the building project? h. What difficulties were encountered during the building project? • The observers' answers can be used to start the discussion, stimulate the students' reflection on the challenges of estimating, and link the simulation with theory.	20 min.
10	***Post-Simulation Debriefing and Discussion Phase*** • During the debriefing and discussion phase, the following questions can be asked to initiate discussion, stimulate exchanges and foster learning: a. What are your impressions? b. What do you think the objectives of this simulation were? c. What have you learned? d. What approach did you take to prepare your estimates? e. What elements are needed to prepare good estimates? i. Information (quality + quantity) & Experience + Expertise • Each of the observers shares their observations with the rest of the group on (1) Estimation techniques used; (2) Building strategies; (3) Team dynamics; (4) Significant events and their management; (5) Difficulties encountered and their management. • Use the spreadsheet to show the various estimates and the gaps between the original and revised versions, as well as the final time. Ask students: f. What do they see? In terms of estimation quality? In terms of meeting the client's needs? • Various techniques and recommendations should be used to increase the effectiveness of the debriefing activity (e.g., Allen *et al.*, 2018; Kolbe *et al.*, 2015).	20 min.

To prepare the project estimation SBT, the following tasks must be performed:

1) Print copies of the *Estimation Grid* (Form 1) – One per person + one per team.

2) Print copies of the *Observation Template* (Form 2) – One per team.

3) Print separate copies of each *Transportation Vehicle – Textual Description* (Form 3). One third of the teams will build the vehicle using the textual descriptions only.

4) Print labels, cut and fold them and put them in a plastic bag for the draw (Form 4).

5) Separate the building instructions, boxes and pieces from the LEGO® sets.

6) Put all the LEGO® sets in well-identified individual reusable plastic bags.

Form 1 – Estimation Grid

Team ID: ____________________

Student name: _____________________

Transportation model built (circle): Airplane Helicopter Truck

Building situation (circle): Textual description Picture (box) Building plan

	Original Estimate	**Revised Estimate**	**Final Time**
Task list (optional)			
Mandatory – Total time (in min.):			

Form 2 – Observation template

Observer's name:

Team ID:

Transportation model built (circle): Airplane Helicopter Truck

Building situation (circle): Textual description Picture (box) Building plans

As an observer, you have three important tasks to perform:

1) Keep track of time and inform the team every 3 minutes.

2) Collect information in relation to the 3 estimate times (original, revised and final) on the Observation Template.

3) Document what is happening in the team you are observing by answering the following five questions:

Question #1: How was the estimation prepared? On what basis? What estimation technique(s) were used?

____

____

____

____

Question #2: What building strategies did the team use?

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Question #3: Describe the team dynamics (e.g., conflict, coordination, communication).

____

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Question #4: What significant events happened during the building project and how were they managed?

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Question #5: What difficulties were encountered during the building project and how were they managed?

Form 3 – Transportation vehicles – Textual descriptions

Textual description of Airplane

• The airplane model will be a replica of the Grumman F-14 Tomcat fighter. A feature of this model is that it has retractable wings. The crew of this airplane is a maximum of two persons.

• The airplane will be 18 cm long by 5 cm high by 13 cm wide when the wings are "closed" (including the fixed rear wing) and 17 cm wide when the wings are deployed (thus, the wings must be mobile).

• The airplane's colours will be opaque yellow, white, blue, grey, and black and semi-opaque yellow, red, green, and black. The yellow colour will be present on the top of the airplane from the engine air intakes (on each side of the cockpit) to the end of the airplane, including the two fins. The airplane's four wings will be white. The blue will cover the outer sides of the airplane and the underside of the cockpit. The grey will be used on the spikes of the airplane fins, the top of the engine (ventilation grid) and the plane's two powerful reactors. The nose of the plane and the lower part of the cockpit will be black. Finally, the semi-opaque colours will be positioned as follows: a yellow light in front of each fin and, by convention, a red light on the port side and a green light on the starboard side.

Textual description of Helicopter

• The helicopter model will be a replica of a cargo helicopter with a retractable winch and, in the cockpit, space for the pilot and co-pilot. This helicopter will be equipped with a freight container with a ring for transportation by air. The helicopter will be 15 cm long by 5 cm wide and 6 cm high. The four blades of the propeller (mobile) on the top of the helicopter will measure 13.5 cm each, while the tail propeller's three blades (mobile) will measure 3 cm each. The freight container will be approximately 5 cm long by 1.5 cm wide and 2 cm high (without the ring) and will include two doors with handles that open.

• The colours of the helicopter will be yellow, white, grey, red, and semi-opaque and opaque black. The freight container will be grey and white. The ring for transporting this box must be black.

• The sides of the helicopter, the bottom of the cockpit, the side of the tail and the belly of the aircraft will all be yellow. White will be used as a signal on the tip of each blade of the main propeller. The nose, the two engines, the top of the rotor of the main propeller and the bottom of the helicopter will be grey. The two air vents in the front and the two exhaust pipes must also be grey. The top of the cockpit, tail and mudguards will be red. The sides of the helicopter will be decorated with a lengthwise red stripe down the middle. The signal lamps to the rear of the engine are also red. Both propellers will be opaque black. The landing gear, wheels (three axles: one front and two rear), and winch (retractable) will also be opaque black. The semi-opaque black colour will be used for the cockpit windows.

• For the freight container, the bottom and the top of the box will be grey, and the walls will be white (including the two doors, which will be located on the sides of the container). Finally, the ring for transporting the container will be black.

Textual description of Truck

• The truck model will be a replica of a Mack truck. The back of the two-seater cabin (without berth) will be a platform for a Robinson R44 Raven helicopter.

• The truck will be 11.5 cm long by 4 cm wide and 7 cm high. The helicopter will be 11 cm long by 3 cm wide and 3 cm high. The diameter of the main propeller of the helicopter (two blades, mobile) will be about 7.5 cm. The tail propeller (three blades, mobile) will be positioned on the starboard side.

• The opaque colours of the truck will be light and dark green, grey, and black. The semi-opaque colours will be black, orange and red. The helicopter will be opaque and semi-opaque orange, and opaque white, grey and black.

• For the truck, the entire cabin and the base of the deck will be light green and dark green. The grey colour will be used for the bumper, deck frame, helipad, both mirrors, smoke stack and handles on the sides of the deck (near the cab) and underneath the truck. The wheels (two axles) and the underside of the truck will be opaque black. The semi-opaque black will be used for the vehicle's windows. Finally, the other semi-opaque colours will used for signal lights: two orange ones on the cabin roof, two yellow ones on each side of the grille, two red ones under the deck behind the mudguards, and two red rear lights.

• The light helicopter will have an opaque orange nose, sides (including skid supports), back and tip of the tail. The cockpit frame will be white, as will the tail and blades of the main propeller. Grey should be used for the engines located on each side of the main propeller rotor and for part of the helicopter's tail end. The landing gear, in this case the skids, the secondary propeller (on the starboard side of the tail) and the propeller hub will be black. The cockpit will be semi-opaque black. Finally, a semi-opaque orange signal light should be positioned on the tip of each blade of the main propeller.

Form 4 – Vehicle and building situations – Labels for the draw

Airplane Textual Description	Helicopter Textual Description	Truck Textual Description
Airplane Image – Box	Helicopter Image – Box	Truck Image – Box
Airplane Building Plans	Helicopter Building Plans	Truck Building Plans

Note: These labels must be cut out with scissors, folded and put into a small plastic bag for the draw (see Table 1, Activity 3).

Form 5 – Spreadsheet used to compile and compare estimates and final times

Simulation Lego - Estimate

Date: XX

Comparative Grid

Teams	Situation	Vehicle (In minutes)	Original Estimate	Revised Estimate	*Final Time	Gap Orig.-Revised	Gap Orig.-Final	Gap Rev.-Final	Gap - % Orig.-Revised	Gap - % Orig.-Final	Gap - % Rev.-Final	**Acheivement of client's needs
#1	Text	Airplane	20	60	60	-40	-40	0	-200%	-200%	0%	2
#2	Image	Airplane	25	30	33	-5	-8	-3	-20%	-32%	-10%	7
#3	Plan	Airplane	16	23,5	27,3	-7,5	-11,3	-3,8	-47%	-71%	-16%	10
#4	Text	Helicopter	30	45	58	-15	-28	-13	-50%	-93%	-29%	1
#5	Image	Helicopter	30	30	37	0	-7	-7	0%	-23%	-23%	6
#6	Plan	Helicopter	17	19,5	16	-2,5	1	3,5	-15%	6%	18%	10
#7	Text	Truck	17	25	31	-8	-14	-6	-47%	-82%	-24%	2
#8	Image	Truck	15	31	29	-16	-14	2	-107%	-93%	6%	7
#9	Plan	Truck	12	10	12	2	0	-2	17%	0%	-20%	10

* The building was stopped after 60 minutes even if one team had not finished

** Scale used: 1 = Client's needs have NOT BEEN MET AT ALL and, 10 = Client's needs have been COMPLETELY MET

APPENDIX B – TEACHING NOTES – FOR STUDENT

The following section presents the general information which should be provided to the students during the simulation.[11]

Simulation context – For students

You and your teamwork for a major manufacturer in the transportation industry. You have signed a contract for the construction, in an international competition, of new transportation vehicles: a helicopter, an airplane and a truck. This contract is important for your company! The winning firm will be offered a contract to build 150 helicopters, 150 airplanes or 150 trucks for the United Nations. In this contest, you must:

- Allocate roles and responsibilities to each team member (see Table A2);
- Estimate the tasks and time needed to build the transportation vehicle assigned to your team and start to complete the Estimation Grids, first individually, then as a team (see Form 1);
- Build the transportation vehicle respecting the client's requirements;
- Compare your building times.

Simulation instructions and criteria – For students

During the simulation, the following instructions must be respected:

- You may not use the Internet to search for additional information (e.g., images, building instructions, etc.);
- You may not spy on other teams either;
- Materials required: Paper and pencil, Estimation Grids (Form 1), timer and Observation Template (Form 2);
- Do not lose any of the LEGO® bricks, or your team will be disqualified;
- Evaluation criteria for your transportation vehicle (Scale from 1 = not at all to 10 = perfect):
  - Completed project;
  - Product meets the client's requirements (e.g., how similar is it to the original LEGO® model?).
- In each team, the following roles and responsibilities must be allocated (see Table A2):

Table A2: Roles and responsibilities

Team members (2 or 3 students)	Observer (1 student)
1. Provide information for estimation. 2. Build the model.	1. Start stopwatch + inform team every 3 minutes. 2. Collect information related to the project building estimates: Original, Revised and Final. 3. Complete the Observation Template (Form 2) by taking notes on: (1) Estimation techniques used; (2) Building strategies; (3) Team dynamics; (4) Significant events and their management; (5) Difficulties encountered and their management.

[11] The elements in the Students' Section were presented on PowerPoint slides in our SBT.

Simulation Instruction and criteria – For students

The simulation will comprise three main phases:

1) Estimation and building phase

   a. Estimation phase: 10 minutes / all teams

      i. Teams with the "Textual description" – Exit the classroom to prepare your estimate

   b. Construction phase: Build – but within the time boundary / all teams

2) Team presentation phase

   a. Vehicle model: 1 minute / team

   b. Challenges and strategies: 2 minutes / team

3) Group debriefing and feedback phase: 20 minutes

APPENDIX C – QUESTIONNAIRE ITEMS

Experiential learning perception (28 items) (Clem *et al.*, 2014)

Each item is measured using a 7-point Likert scale where 1 = Strongly Disagree and 7 = Strongly Agree

Authenticity subscale items (5 items)

1) The setting where I learn helps me understand the material better.

2) I expect real-world problems to come up during this learning experience.

3) The environment I learn in does not enhance the learning experience (Reverse).

4) The learning experience requires me to interact with people other than students and teachers.

5) I expect to return to an environment similar to the one where this learning experience occurs.

Active learning subscale items (7 items)

6) I am stimulated by what I am learning.

7) The learning experience requires me to do more than just listen.

8) The learning experience is presented to me in a challenging way.

9) I find this learning experience boring (Reverse).

10) I feel like I am an active part of the learning experience.

11) The learning experience requires me to really think about the information.

12) I am emotionally invested in this experience.

Relevance subscale items (9 items)

13) I care about the information I am being taught.

14) The learning experience makes sense to me

15) This learning experience has nothing to do with me (Reverse).

16) This learning experience is enjoyable to me

17) I can identify with the learning experience.

18) This learning experience is applicable to me and my interests.

19) My educator encourages me to share my ideas and past experiences.

20) This learning experience falls in line with my interests.

21) I can think of tangible ways to put this learning experience into future practice.

Utility subscale items (7 items)

22) This learning experience will help me do my job better.

23) This learning experience will not be useful to me in the future (Reverse).

24) I will continue to use what I am being taught after this learning experience has ended.

25) I can see value in this learning experience.

26) I believe this learning experience has prepared me for other experiences.

27) I doubt I will ever use this learning experience again (Reverse).

28) I can see myself using this learning experience in the future.

Quality of their team experience (9 items) (McCreery, 2003)

Each item is measured using a 7-point Likert scale where 1 = Strongly Disagree and 7 = Strongly agree

1) The workload was fairly balanced across all team members.

2) Team members cooperated well throughout the exercise.

3) Our team worked through the exercise in an efficient manner.

4) Team members all participated equally in the team decision-making process.

5) Our team maintained a pleasant working atmosphere.

6) Our team worked out disagreements in an equitable manner.

7) Team members were highly motivated to perform well in the exercise.

8) Overall, I am satisfied with my team experience.

9) I would be willing to work with my team on an actual project in the future.

Team dynamics and students' satisfaction level (4 items) (Barki & Hartwick, 2001)

Each item was measured using a 11-point scale where –5 = Very Unsatisfied and 5 = Very Satisfied.

Your level of satisfaction with…

1) ... the composition of the team.

2) ... to the functioning of the team.

3) ... how the work was managed.

4) ... the model that has been developed.

Open-ended questions (4 items)

Q1 – In your opinion, what are the ***advantages*** of this LEGO® estimation simulation?

Q2 – In your opinion, what are the ***disadvantages*** of this LEGO® estimation simulation?

Q3 – What is your ***level of satisfaction*** with the simulation you just experienced?

Q4 – What did ***you learn from*** this workshop that you can ***apply in your professional*** or academic activities?