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Process Selection and Appropriate Inspection Regime through a Card Game

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ABSTRACT

In this paper, we describe an active learning tool in the form of a card game, which illustrates process selection and appropriate level of inspection for a multi-stage production process. Students in the first undergraduate level quality management class played it over several offerings. Based on the lessons learned, the game was modified to incorporate costs and criteria for process selection and was demonstrated in one undergraduate and one graduate class. Based on the experience, it was further refined and is ready for prime time. Theoretical expectations are also presented.

KEYWORDS: Card game, process strategy, quality, inspection, active learning

INTRODUCTION

Process selection is one of the typical topics covered in an introductory course in operations and supply chain management. Using probability concepts to assess the value of in-process inspection is a topic covered in quality management classes. Probability distributions, specifically binomial distribution plays a central role in designing quality control systems, and is a topic covered in typical quality management classes. In this paper, we discuss a game that we designed to address these questions by using an active learning method in a group setting.

Probability distribution is an abstract concept to many students and it is difficult to teach that using lectures alone. Distributions play a crucial role in developing tools to build and manage quality control systems. In a multi-stage production system, it may sometimes be worth inspecting during intermediate steps to detect defectives so that they may be fixed or abandoned before incurring the full cost of production. Concepts of probability of finding a defective, cost of fixing, decision to fix or abandon, are crucial in designing or choosing from a set of available production processes.

In general, there is typically more than one process to manufacture a product. Costs and the needs for the organization will generally guide us to choose the best among several available processes. On many occasions, costs may be cut and dry, however it may depend on intermediate events/outcomes in a production process. The outcomes from each stage of a production process may be defined in probabilistic terms. Hence, the problem may call for using some type of decision tree or expected value analysis to arrive at the right decision. Further, a real-life situation may not provide crisp probability distributions to apply well-known techniques to arrive at an optimal decision. In this game, we present an active learning setting, where the student learns by doing. Deming's Bead experiment is a pioneering example of active learning to illustrate the inherent process variation. In one implementation, there is a tub with 100 red beads (stands for "bad") part and 900 white beads (stands for "good" part) and a "worker" is supposed to randomly scoop 50 beads at a time (synonymous to producing 50 units) and the "inspector" checks the quality of the worker's production. An unsophisticated observer may attribute the quality of finished goods in this process to the worker, though all of us know that is not the worker's fault or skill that produced good or poor outcomes in this experiment. However, if you play it in a typical class, it takes some time before students get the point. Deming's funnel experiment, where a marble is dropped through a funnel on to a paper below with a target mark and the goal of the experiment is to drop the marble in such a way that it stops on the target, is another method to explain randomness. After various "intuitive" trials the experimenter realizes that one needs a scientific basis to decide on where to set the funnel to achieve the objective. The card game described in this paper is similar in spirit to the fore-mentioned examples, in that the player would get a good grasp of variables that affect the process selection and appropriate level of inspection needed to achieve the objective of choosing the right process and inspection regime in a production setting, after several rounds of play.

Next, we review other work that may be in the same spirit as this paper, in terms of emphasis on active learning and present it in section 2. The card game has three versions. The basic version and our in-class experience with it is described in Section 3. Based on this experience, the game was modified and used in two more sections. The modifications and experience are discussed in Section 4. Section 5 presents the theoretical probabilities, how we arrived at it and how they may be used to judge the answers produced by the students. Section 6 presents some future modifications and conclusions.

LITERATURE REVIEW

The accommodation of contrasting learning styles has been the subject of educational research for decades. A vast range of active learning tools have been widely tested for their efficacy and practicality with mixed results (Randel & Morris, 1992). A number of empirical studies suggest that the design, delivery and timing within the curriculum are determinants of successful implementation (Raja, 1966; Ranchhod, et.el., 2014). In many cases, this success is defined as a significant increase in student's retention of information – typically measured through the comparison of exam scores (Mikakayeva, 2016). However, many advocates of active learning theory argue that the potential benefits extend far beyond exams. Just as on-the-job training is required for many tasks, there are some ideas that cannot be effectively expressed explicitly and require a tacit understanding that can only be transferred through an activity (Garris, et.el., 2002; Spizizen & Hart, 1985).

Critics have argued that such tacit knowledge is often untestable in a non-vocational setting, and therefore, evidence of efficacy is equivocal (Hardy, et.al., 2014; Holt & Capra, 2000). While acknowledging this issue, constructivist advocates argue that a guiding principle of active learning is to impart "life lessons" rather than to merely improve exam scores (Baker, et.al., 2005; Bragge, et.al., 2010). Nevertheless, the integration of classroom activities, once the mainstay for elementary school education, is now becoming more widely accepted in secondary and university curriculums. The shift toward hybrid courses (combination of classroom and

Internet delivery) is an example of this acceptance (Bell & Kozlowski, 2008; Lovelace, et.al.., 2016).

Evidence suggests that the best classroom activities have a mild to moderate learning curve, require a measured level of periodic guidance, are of the proper duration, and closely tied to a main learning objective (Smith & Doren, 2004; Cadotte & MacGuire, 2013). Activities that are too complex will tend to alienate many students. With too little guidance, students may miss the point of the activity, while too much may be oppressive (Webb, et.al., 2014). Yet, instructors also need to carefully supervise the activity to ensure that the proper pace is maintained (Hartman, et.al., 2013). Ideally, the activity should further the transferal of material as effectively, or more effectively, than other means (i.e. primary lectures). Most importantly, the activity must be designed in such a way that leads the students to an understanding of a learning objective (Breen & Boyd, 1976). Some have argued that the learning objective should not be immediately obvious to the students. As with the Socratic method, students “discover” the purpose in a moment of epiphany (Larson, 2013).

While the design of the activity discussed in this paper has evolved through experimentation, the original inspiration came from Deming’s funnel experiment (Deming, 1986). In most situations, a direct recreation of Deming’s experiment would not be practical, and perhaps because of this, a number of online applications have been developed to simulate the experience. These simulations are interesting, but the lack of active student involvement limits their educational value (Coleman, 1999). Other attempts have been made to adapt the funnel experiment through more active computer simulations (Hanna, 2010), but to fully embrace the tenets of active learning theory, something with a more tactile connection was desired. Standard playing cards are a perfect solution.

Common objects (such as dice or playing cards) can be very effective teaching tools. Having previous experience with these objects helps students overcome apprehension regarding an unknown task (Stuebe & El-Shamy, 2001). Playing cards, for example, carry over a number of conventions that provide commonality between team members. Given a deck of playing cards, most students will already be aware of the need to shuffle, the convention of placing unused cards face down, or methods of dealing (Baker, et.al., 2016; Thiagarajan, 1991). For many students, prior experience with playing cards will be positive, and this positive outlook may aid the engagement of the activity (Reese & Wells, 2007). The next section describes the card games.

Basic Card Game and Class Room Experience

There are three versions of the card game. All versions use four processes using a standard deck of 52 cards described in Exhibit 1.

Exhibit 1: Basic Game

A widget requires four sequential operations to be completed to produce a finished unit. The first operation is always defect free. The second and subsequent operations have a positive probability of being performed defectively. Assembling four defect free subassemblies correctly produces a defect free final assembly. The process is a batch process with a given starting batch size, but the yield is process dependent. The four production processes are mimicked by the following card game. A process batch is a regular 52-card deck (no jokers) of playing cards.

Production process #1**:**

a) deal four cards, one at a time, face up
b) if the four cards:
   i. are the same color, count as one good product
   ii. have any card of different color, count as bad
c) repeat until the deck is dealt

Production process #2**:**

a) deal cards, one at a time, face up
b) the first card of different color
   i. stop dealing for that product
   ii. remove product cards
c) repeat from step a
d) count all sets of four cards of the same color as one good product
e) repeat until the deck is dealt

Production process #3**:**

a) deal cards, one at a time, face up
b) the first card of different color, remove and deal next card
c) at the next off color card, stop and scrap product
d) count all sets of four cards of the same color as one good product
e) repeat until the deck is dealt

Production process #4**:**

a) deal cards, one at a time, face up
b) the first card of different color, remove and deal next card
c) repeat for each off color card
d) count all sets of four cards of the same color as one good product
e) repeat until the deck is dealt

The basic game was used in four sections over a period of two years. It generally took one class period (about 75 minutes) to play the game. The instructor watched over the process, interactions, and answered all questions regarding the game. See exhibit for the rules of engagement.

Exhibit 2 Rules of Engagement:

Each team needs to select a supervisor, a production worker, production recorder, and a quality inspector. The remaining members are to observe and note any changes that could affect the production outcome. The four specific roles are described below:

1) The supervisor must keep the process on task and achieve a high rate of output. This person will report the output for each round on the master schedule. This role may also change personnel as deemed necessary to maximize good product output.
2) The production worker is to deal the cards to produce good product at required output levels. This position is under constant scrutiny for higher production output.
3) The production recorder will keep count of good and bad product (first production run) and just good product for the subsequent production runs.

4) The quality inspector will check components (shuffle cards) after each round. The shuffle is to remain totally random with no "stacking" the deck.

Gaming Process: Each team will receive a deck of playing cards. These cards are to be shuffled by the quality inspector then handed to the production worker. The production worker will deal four cards, face up and the recorder will track the good and bad product as noted in the job description above. This process will continue until the entire deck has been dealt, which will complete one round. The quality inspector will then reshuffle for the next round. The team supervisor will report the output while the team is preparing and starting the next round. After six rounds the instructor (as instructor) will advise you of how to proceed. The instructor is "upper management" only during the production runs or for reporting of output. All recording will be noted on the team spreadsheet provided. All teams will report each rounds output on the master schedule of upper management. A typical class had 8 groups and % of good parts per round and the range of good parts among the 8 groups is reported in Table 1.

At first students were intrigued about how many good parts they will get, how many they should get on an average, if they get more, are they doing something better etc. After some rounds, the students started to understand the purpose of the game and concentrated on the task at hand.

Table 1: Results of Class Room Performance

Date	1/29/2015	9/9/2015	1/26/2016	9/8/2016
Average # of good parts using Process #1	18.13%	15.38%	10.99%	11.54%
Range of good parts using Process #1	43.59%	17.95%	16.67%	8.97%
Average # of good parts using Process #2	18.68%	21.25%	11.90%	19.23%
Range of good parts using Process #2	14.10%	28.21%	14.10%	15.38%
Average # of good parts using Process #3	35.53%	32.05%	26.01%	30.77%
Range of good parts using Process #3	21.79%	16.67%	33.33%	10.26%
Average # of good parts using Process #4	62.82%	61.17%	50.37%	58.79%
Range of good parts using Process # 4	6.41%	7.69%	55.13%	32.05%

At the end of the game, they were asked to answer six questions. The student responses are summarized in Table 2.

Table 2: Student Responses:

Question 1: Did **quality**, as a separate department or function, have an impact on the outcome?
No: it was just random;
Yes: improved by 44%; had a huge impact on the outcome; As we threw bad batches (components) out quality improved.
indirect impact: how many cards were in the deck determined how many good products
Question 2: Did the **supervisor** have any impact on the outcome in any of the production processes?
No: the supervisor just reported end results; supervisor did not affect the outcomes because of lack of power;
Yes: Mistakes were corrected; implemented a policy that increased good parts by 5-10 per round; He talked to production and kicked them into gear; he ensured that we stayed on task.
Question 3: Treating process change as "**upper management"** pressuring the supervisor to increase output, discuss impact.

made it easier to control quality throughout production; provided us with different procedures to help improve quality of the line;
No: Nothing changed
Question 4: What had the greatest impact on the outcome of any of the production processes? (component quality, personnel changes, process changes):
Exchange of bad part till good product was produced; Quality inspector; (other similar responses).
Question 5: Summarize what you have learned from this exercise.
When quality is their own department and not integrated into production it has no effect; We learned that fixing quality of the product as we made it helps us improve our chances of having a good product; We learned it is important to change the method to increase quality. Also, it is better to stop the process and make corrections rather than throwing away the entire product; We reduced the variation as we revised the process.
Question 6: What would make this workshop better?
Allow quality to make decisions in the order of the cards; Speed up production through breaking down tasks to a more granular level; No rigging the deck; overall it was a fun way to learn the quality concept hands on; Maybe add an opportunity to have the students think of a solution for improvement, adding an incentive to whomever improves the most to get us (teams) more involved and add more competition.

At first, looking at Table 1, it is clear that wide variations will be resulting in a class setting, even assuming well shuffled cards at all times. Since the game was not competitive, policing for well shuffled cards was not paramount. But the variation in results did surprise some students. There was one team that had such marked improvement that the instructor intervened to find the “inspector” had stacked the deck, thus an instructional modification was introduced. Studying the responses reveals that students approach it from different angles. Not everyone understood the underlying variation and randomness that causes the defects and responsible for the poor or good outcomes. As we moved from process 1 to 2 to ultimately 4, it became clearer and also illustrated the importance of developing processes improvements. Since there were no cost or time consequences to choosing the process, clearly process 4 was the best.
That led us to design the next version of the game, incorporating process selection issues and cost of repair vs. abandonment issues. These are discussed in the next section.

Modified Card Game and our Experience

The simple card game did not have enough data to choose between processes or make decisions on when and whether to inspect. Hence, the game was modified to include costs and is described in Exhibit 3.

Exhibit 3: Process Selection Game:

<u>Process batch</u>
All processes are run in batches and a process batch corresponds to a well shuffled deck of 52 cards. The fixed cost associated with a process batch is $500. The yield per batch will vary depending upon the process chosen. One of your challenges will be to assess the yield based on the process description. Production processes referred to below correspond to the card game described in Exhibit 1.

Process #1: (Inspect at the end): Inspect at the end of the fourth and final operation and discard the product if found defective. Continue the production of the next unit. Ship all defect-free final assemblies. Relevant cost of this process is $5.00 per shipped unit.

Process #2: (Inspect during production): At the occurrence of the first defect, discard the partially or fully completed product and start the production of a new unit from scratch. In this process, inspection is done at every stage starting at 2. Ship all the defect-free final assemblies. Relevant cost of this process is $10.00 per shipped unit.

Process #3: (Inspect during production): At the occurrence of the first defect, remove and replace the last added component. Continue the process, at the occurrence of a second defect, discard the partially or fully completed product and start production of a fresh unit. Ship all defect-free final assemblies. Relevant cost of this process is $20.00 per shipped unit.

Process #4: (Inspect during production) At the occurrence of a defect, remove the defective component and continue the process, keep assembling, inspecting and removing defective part as needed, until the assembly is completed. Then move on to the next assembly. Ship all final assemblies found non-defective at all stages. Relevant cost of this process is $40.00 per shipped unit.

Questions:
You have a total of 6 process batches.

1. Estimate the number of defect-free final assemblies that will be produced by using each of the four processes described.
2. Choose the process that will maximize the number of defect-free final assemblies produced.
3. Choose the process that will minimize the cost per defect-free final assembly produced.

This version of the game was run in both an undergraduate and a graduate class in Quality Management. Class results of the graduate class is listed in Table 3.

Table 3: Results from the graduate Class

	Mean and range of "Good" parts per batch under each process			
Process	1	2	3	4
Mean	9.764706	12.17647	19.70588	40.76471
Range	4	12	22	14

For the current version of the game, it turns out that process 4 will produce maximum number of good batches and process # 4 also produces the lowest cost per unit of good product produced. This was recognized correctly by all students in question #2 and by about 75% of the students for question #3. The undergraduate students played in groups of 4 and produced similar results. In order to provide a more challenging and nuanced approach, we produced the next version presented in Exhibit 4. We plan to test this in Summer and Fall and report the results.

Exhibit 3: Inspection Mode and Process Selection Game:

Process batch**:**
All processes are run in batches. The fixed cost associated with a process batch is $100. The yield per batch will vary depending upon the process chosen. One of your objectives will be to assess the yield based on the process description.

Process #1**:**
(Inspect at the end): Inspect at the end of the fourth and final operation and discard the product if found defective. The defect may be at any stage of production and the cost of raw materials is $20.00 per completed assembly, good or defective and the cost of inspection is $5.00 per unit. Ship all defect-free final assemblies. Continue the production of the next unit.

Process #2**:**
(Inspect during production): At the occurrence of the first defect, discard the partially or fully completed product and start the production of a new unit from scratch. In this process, inspection is done at every stage starting at 2. Cost of inspection is $5.00 per stage and cost of discarded raw materials will be $10.00 per completed stage and you incur the cost for each stage that was built up. Completed unit costs $20.00 per unit. Ship all defect-free final assemblies.

Process #3**:**
(Inspect during production): At the occurrence of the first defect, remove and replace the last added component. At the occurrence of a second defect, discard the partially or fully completed product and start production of a fresh unit. Cost of inspection at stage 2 and beyond is $5.00 per unit at each stage and cost of abandoning is $15.00 per completed stage (including each stage that was discarded due to defect). Cost of completed unit is $20.00. Ship all defect-free final assemblies.

Process #4**:**
(Inspect during production): At the occurrence of a defect, remove the defective component and keep assembling, inspecting and removing defective parts as needed, until the assembly is completed. Then move on to the next assembly. Each inspection costs $5.00 and each discarded part costs $20.00. Each completed unit costs $20.00. Ship all defect-free final assemblies. The students answer the same questions as in Exhibit 2.

Discussion of results

The game was initially developed with emphasis on processes, repair/discard, and to understand group dynamics of execution in a class room setting. In the beginning, it did not have any cost figures. The assignment was simply to report on the number of good units produced and what process should be chosen and comments on the game and the results. The original version was well received and taught the students the importance of variation, assignable cause, difference between inherent variation in the process and operator induced variation (assignable cause) and potential remedies to fix it. The subtler points were explored in class after the game playing.

Another aspect of the game was to estimate the number of “good” assemblies that would be produced given the process description. This can be estimated using binomial distribution and some simplifying assumptions. We took the opportunity to explain the probability and distribution concepts using the game as a medium and it went very well. The students were curious as to how to find the answers without elaborate game playing, so that one can modify the steps, costs, and other crucial parameters and evaluate the best process. This led us to estimate the theoretical number of good units that will be produced in each process. This may be used to verify the class work as well as assigned as an extended class problem.

Theoretical results

Given six rounds, the expected values for process yield, the number of replacement cards needed and the number of inspections are as follows. If we make the assumption that the cards will be drawn one at a time and replaced before drawing the next card, the probability calculations get a little easier. It might be a good approximation to use for the undergraduate students. Hence in this section, we provide results for with and without replacement.

Table 4

With Replacement

	Expected		
	Yield	Replacements	Inspections
Proc 1	9.75	0	78
Proc 2	9.75	0	198.55
Proc 3	24.38	0.875	236.36
Proc 4	44.57	3	267.43

Without Replacement

	Expected		
	Yield	Replacements	Inspections
Proc 1	8.614	0	78
Proc 2	8.614	0	197.53
Proc 3	21.96	0.890	236.27
Proc 4	42.37*	3.156*	281.34*

* found through simulation

The probability distributions for each of the processes are as follows:

Table 5

	With Replacement		Without Replacement (initial product)	
Process 1	X	P(X)	X	P(X)
	Bad Product	0.875	Bad Product	0.890
	Good Product	0.125	Good Product	0.110
Process 2	X	P(X)	X	P(X)
	Bad Product	0.875	Bad Product	0.890
	Good Product	0.125	Good Product	0.110
Process 3	X	P(X)	X	P(X)
	Bad Product	0.6875	Bad Product	0.710
	Good Product	0.3125	Good Product	0.290
Process 4	X	P(X)	X	P(X)
	Bad Product	0	Bad Product	0
	Good Product	1	Good Product	1

Conclusions and Future directions

In this paper, a card game is described that could teach students about process selection and evaluation of inspection costs. A simpler version was extensively used and tested which gave us valuable lessons in improving the game. The whole game could be played in one 90-minute session, followed by a take homework assignment which might take about 60 minutes. Both taught valuable lessons in process selection, deciding on the appropriate level of inspection and to a clearer understanding of binomial distribution.

The game may be modified to illustrate other probability distribution concepts by changing the game to getting a sequence as an acceptable or “good” product as opposed all of the same color. It will teach about permutation, combination and probability in a fun and active learning format. It could also illustrate other types of process selection and inspection issues.

References

Baker, A., Navarro, E. O., Van der Hoek, A. (2005). An experimental card game for teaching software engineering processes. Journal of Systems & Software, 75(1/2), 3-16. doi:10.1016/j.jss.2004.02.033

Bell, B. S., & Kozlowski, S. J. (2008). Active Learning: Effects of Core Training Design Elements on Self-Regulatory Processes, Learning, and Adaptability. Journal of Applied Psychology, 93(2), 296-316.

Bragge, J., Thavikulwat, P., & Töyli, J. (2010). Profiling 40 Years of Research in Simulation & Gaming. Simulation & Gaming, 41(6), 869-897. doi:10.1177/1046878110387539

Breen, W., & Boyd, J. (1976). CLASSROOM SIMULATION AS A PEDAGOGICAL DEVICE IN TEACHING MONEY AND BANKING. Journal of Financial & Quantitative Analysis, 11(4), 595-606.

Cadotte, E. R., & MacGuire, C. (2013). A Pedagogy to Enhance the Value of Simulations in the Classroom. Journal For Advancement Of Marketing Education, 21(2), 38-40.

Coleman, D. W. (1999). Adapting Deming's Funnel Experiment to a content-specific area. Simulation & Gaming, 30(1), 8.

Deming, W. E. (1982), Out of the Crisis, Cambridge, MA: MIT Center for Advanced Engineering Study.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. Simulation & Gaming, 33(4), 441-467.

Hanna, M. D. (2010). Using a Spreadsheet Version of Deming's Funnel Experiment in Quality Management and OM Classes. Decision Sciences Journal of Innovative Education, 8(1), 137-142. doi:10.1111/j.1540-4609.2009.00248.x

Hardy, J. H., Day, E. A., Hughes, M. G., Wang, X., & Schuelke, M. J. (2014). Exploratory behavior in active learning: A between- and within-person examination. Organizational Behavior & Human Decision Processes, 125(2), 98-112. doi:10.1016/j.obhdp.2014.06.005

Hartman, N. S., Watts, C. A., & Treleven, M. D. (2013). Appreciating the Complexity of Project Management Execution: Using Simulation in the Classroom. Decision Sciences Journal of Innovative Education, 11(4), 323-334. doi:10.1111/dsji.12016

Holt, C. A., & Capra, M. (2000). Classroom Games: A Prisoner's Dilemma. Journal of Economic Education, 31(3), 229.

Larson, E. C. (2013). Teaching Tip Utilizing Classroom Simulation to Convey Key Concepts in IT Portfolio Management. Journal Of Information Systems Education, 24(2), 99-104.

Lovelace, K. J., Eggers, F., Dyck, L. R. (2016). I Do and I Understand: Assessing the Utility of Web-Based Management Simulations to Develop Critical Thinking Skills. Academy Of Management Learning & Education, 15(1), 100-121. doi:10.5465/amle.2013.0203

Mikalayeva, L. (2016). Motivation, Ownership, and the Role of the Instructor in Active Learning. International Studies Perspectives, 17(2), 214-229. doi:10.1093/isp/ekv001

Raja, A. P. (1966). A STUDY OF THE EDUCATIONAL VALUE OF MANAGEMENT GAMES. Journal Of Business, 39(3), 339-352.

Ranchhod, A., Gurău, C., Loukis, E., & Trivedi, R. (2014). Evaluating the educational effectiveness of simulation games: A value generation model. Information Sciences, 26475-90. doi:10.1016/j.ins.2013.09.008

Randel, J. M., & Morris, B. A. (1992). The effectiveness of games for educational purposes: A review of recent research. Simulation & Gaming, 23(3), 261.

Reese, C., & Wells, T. (2007). Teaching academic discussion skills with a card game. Simulation & Gaming, 38(4), 546-555. doi:10.1177/1046878107308063

Smith, L., Van Doren, D., (2004). The Reality-Based Learning Method: A Simple Method for Keeping Teaching Activities Relevant and Effective. Journal of Marketing Education, 26(1), 66-74.

Spizizen, G., & Hart, C. L. (1985). Active Learning and the Case Method: Theory and Practice. Cornell Hotel & Restaurant Administration Quarterly, 26(2), 63.

Stuebe, G., El-Shamy, S. (2001) Card Games for Developing Service. Industrial & Commercial Training, 33(4), 145-146

Thiagarajan, S. (1991). GARBAGE: A card game that simulates the trade-off between competition and concern. Simulation & Gaming, 22(1), 112.