Revolutionizing Financial Engineering Education: Simulation-Based Strategies for Learning

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Section 1: Introduction to Microstructure

Financial engineering is a critical aspect of contemporary markets, and its pedagogy of the utmost importance to producing the next generation of market participants and regulators. Lecture-based education dominates today's universities; this paper will explore its weaknesses and suggest simulation-based education as more effective method of teaching. Especially in the field of financial engineering, a simulation-based approach can portray a subject's dynamics to a student more comprehensively than any number of lectures or problem sets, making students more capable when dealing with those same concepts in practice.

Today, machines have largely assumed the role of humans on the trading floor, allowing transactions to be made faster and across multiple markets simultaneously. From near nonexistence in the mid-90s, by 2009 algorithmic trading had grown to account for as much as 73% of U.S. trading volume¹⁴. These relatively new players in the market utilize very fast computers and have the ability to trade in a matter of milliseconds, giving them the potential to precipitate needless erratic and unforeseen price movements. In order to be able to keep up with, and possibly foresee, such events, it has grown critically important for financial engineers to have a deep understanding of the field of market microstructure.

Market microstructure refers to the engineered set of processes and outcomes of exchanging assets under a specific set of rules²⁴. The study of microstructure by financial engineers is fundamental to both the design of sound and successful trading strategies and the rules and regulations that affect trading, which are built upon basic economic principles. With millions of trades flowing per second, the undertaking is predictably complicated. Each of these trades requires a match of buyer-with-seller, but with thousands of computers involved in the process, the details of the matching process often gets obscured, and it is arduous to trace exactly who did what. As the speed of order flow and transactions accelerates, the traceability of the underlying trades will continue to make regulation exceedingly difficult. This opens the door to sudden, massive market movements that can be needlessly damaging to many market participants.

These movements are not necessarily all recent. One such instance that sparked the first major research in the field was “Black Monday,” on October 19, 1987, when the Dow Jones plunged 508 points, or 22% of its total value. Although the panic has been attributed to several different causes, among them computer-driven and derivatives trading, the inability to analyze the microstructure of the markets at the time has kept scholars from being able to determine the true cause behind the brief crash¹⁶. That was in 1987; on May 6, 2010, the same thing happened, with the Dow Jones plummeting 10%, or about 1,000 points, and then regaining it all in a matter of minutes²⁶. This was infamously dubbed “The Flash Crash”¹⁸. Prices rebounded less than 30 minutes later, wiping out nearly all losses and leaving observers with many unanswered questions.

These crises all highlight many issues in the structure of financial markets, but one fundamental problem underlying these issues is a lack of familiarity with financial engineering principles. This paper will, therefore, stress the importance of financial engineering education and examine the most effective method of expanding it through the use of agent-based market simulations. The next section of this paper will cover existing education methods for the field. The third section will describe how simulation-based methods are more effective than traditional teaching practices. The fourth section will present an experiment incorporating a simulation on a specific topic within microstructure. Finally, the fifth section will summarize conclusions. Perhaps with knowledge gained through exposure to more effective education methods, a new generation of traders and regulators can better design markets and adjust their operations to mitigate the negative effects of future crises.

Section 2: Overview of Current Education Systems

This section will review how market microstructure is currently taught in financial engineering courses and briefly survey methods used currently to augment courses to incorporate simulations into education. It is worth noting that while a plethora of simulation papers have been written on such topics as medical education and military strategy, only a limited number of papers have been written advocating simulations in financial engineering education; none of these extend into such complicated topics as market microstructure²⁷.

Textbooks and syllabi of existing coursework on the topic of microstructure show that current education models adhere to rigorously mathematical interpretations of the material. They communicate an understanding of markets through explanations of succeeding market models, each defined by precise mathematical equations and theoretical limitations. Joel Hasbrouck's *Empirical Market Microstructure*¹¹, one of the leading texts in the field, is written from such a mindset, wherein theory is represented through equations meant to formulaically describe auction templates and price movement models. Accordingly, a number of course curricula on the topic of market microstructure are structured to simply teach students about the different types of mathematical and theoretical models^{1 12}. As a result, students' abilities to gain a deep fundamental and comprehensive grasp of the underlying principals of market microstructure in a timely manner can be undermined as they are reliant on just this limited type of coursework.

Traditional education methods used to evaluate the quality of learning seem limited for assessing financial engineering education. Such stratified models of learning were developed from the empiricist philosophies of English philosopher and economist, John Locke^{19 21}. They uphold that the body of knowledge is a compilation of ideological building blocks, basic ideas that supposedly do not change. In this context, the Roll Model and various auction models taught in microstructure courses would be the building blocks that compose financial engineering education¹². These models, however, do not provide adequate consideration of important imperfections of financial theory⁴. As a result under traditional assumptions, quality of learning seems to be measured as simply

the number of basic ideas that a student retains regardless of their validity. Hence, traditional testing methods are weak for assessing a student's actionable, practical knowledge, especially in new fields where theories are constantly being revised and renewed. Once these assumptions are removed, the philosophy behind traditional education methods collapses, opening the door to a more process-based and experiential view of learning.

Experiential education, or simulation-based education, is not necessarily a new concept; in fact, it has already gained a significant amount of acceptance in disciplines such as medicine²⁷. In financial engineering, while simulation has been recognized as an essential tool in the field²⁹, its application in the educational process has been limited. For example, Mitchell, Hunsader and Parker²³ propose a simulation of a futures market to give students a grasp of how to value futures. They establish a lesson plan and even go so far as to define the class size and time required to complete the simulation. Similarly, Hull, Kwak and Walker¹⁵ develop a simulation-based lesson to teach the intricacies of IPO management and establish all the same metrics. Stretcher and McLain³⁰ flip the process by developing a lesson wherein the students themselves must program a simulation to calculate net present value.

Observably, there exist a number of singular simulation proposals for individual topics in relatively introductory finance. However, none go so far as to simulate more complex processes to enable evaluation of the efficacy of various auction models or the effects of rules and regulations placed upon different markets and traders. As such topics

are critical to enabling knowledgeable market participants and regulators to avoid crises such as the Flash Crash, simulations as part of education in this field are an excellent means of conveying an appreciation of market microstructure at a level sufficient to one day enable more viable management of markets.

The remainder of this paper shall serve as an argument as to why the benefits associated with simulation-based education outweigh its costs. The discussion presented views traditional methods as offering theoretical learning, presenting material in terms of symbolic and often mathematical theories. On the other hand, simulation-based methods offer more conceptual learning based on a comprehensive set of interactive concepts instead of just theories.

Section 3: Proposal of Simulation-Based Education for Financial Engineering

Simulation-based education helps overcome some of the weaknesses of traditional, theoretical forms of teaching. In suggesting this solution, a few objectives are addressed. The largest of these would be to provide students with a deeper understanding of the dynamics of the system in question. Another major objective is to reform education as to not cater specifically to students who learn theoretically in preference to those who learn conceptually. Finally, simulation-based education should add a conceptual perspective to symbolic forms of information conveyance.

Any viable form of teaching must present the applications of theory along with the theory itself. While theory is essential, it alone may not provide a mastery of the subject at hand. Accordingly, understanding the appropriate equations does not always translate into being able to effectively implement those same equations^{9 17}. Solely symbolic methods of teaching encourage students to memorize instead of analyze. Although completing practice problems may force some level of implementation, students need to develop a functional understanding of concepts in a dynamic environment where multiple perspectives and operational themes of the concept are tested¹⁷. This is especially the case for the complex mathematical concepts found in financial engineering and market microstructure. Hence, an effective simulation-based education methodology must put theories in practice to teach not only their properties, but also their interactions with the real world.

Students that learn through traditional lecture-based methods have no problem with detached equations and broad abstractions, while kinesthetic learners with just as much potential flounder. Professors Jennifer Chiu of the University of Virginia's Curry School of Education and Marcia Linn of University of California, Berkeley's Graduate School of Education⁶ contend that any form of education that caters to one specific style of learning is lacking and highlight that a mix of theory and visualizations defines the ideal balance. Their work finds that simulation-based education can alleviate this bias.

Simulation-based education also adds a conceptual framework to traditionally symbolic methods of teaching³. Gagne and Brown⁹ specifically mention the proficiency

of “teaching machines” in the communication of concepts over the memorization of symbolic theory. This involves applying theory in an actionable form, just as flight simulators take established principles and implement them in a responsive environment. Effectively, simulations must build on an existing theoretical base to provide an intuitive grasp of the theory in practice. The work of multiple researchers, including Byrne, Catrambone and Stasko³, and Kolb¹⁹, shows that visualizations are in no way substitutes for underlying theory; they merely extend static definitions into real-world dynamics.

Despite potential drawbacks, simulation-based education has a number of unique features that can make it an effective supplement to traditional education. The primary benefit of using simulation is that it allows students to play while learning, thereby leading to deep-content knowledge¹⁷. While comparing simulations to “play” may take away from their perceived educational value, it is important to remember that play is one of the most primordial and basic mechanisms for learning²⁸. This is a well-established practice, as evident in military games historically run to train for actual combat. From this perspective, the concept of a lecture appears an artifact of an industrial-era obsession with efficiency²⁸. Games provide a context for participants to learn by action, allowing for failure without consequence²⁸. Ultimately, this gives participants an intuitive feel for the system they are operating in, giving them functional capacity far beyond somebody who has not been exposed to the system in practice.

The three most important aspects highlighted in the literature are that simulations (a) provide immediate feedback in a realistic environment, (b) allow for creative trial-and-error, and (c) get students emotionally involved⁸.

The immediate feedback offered by interactive visualizations is key to the above. Whereas theory- and lecture-based education has no functionality to instantly inform students of whether their understanding of the material is right or wrong, simulations and games provide real-time feedback to students while they are still focused on the topic at hand. This is important because students typically enter attention lapses at intervals of less than 5 minutes², so any feedback that takes significantly longer to appear is allowing the students' attention to wander and their focus to be lost. Research by Bunce, Flens and Neiles² also shows that lapses occur more frequently in lecture settings. Simulations can decrease the prevalence of these lapses with a constant flow of new, easily digestible data.

Additionally, simulations provide a more realistic view of various systems, incorporating imperfections found in actual practice. For example, in the realm of finance, many mathematical models tend to give up accuracy in order to attain precision, which ultimately leads to giving students information that is either inaccurate or inapplicable²⁹. While no model or simulation can perfectly replicate real events, simulations can better portray the overall applicability of these models while still accounting for possible imprecisions in practice.

By providing instantaneous feedback in a realistic environment, simulations allow participants to behave creatively within digital worlds²⁸. Within these worlds, students have the chance to take a comprehensive view of the system they are studying and to operate with all of the system's aspects in play. To that end, simulations are critical because they allow the full portrayal of a system. On the other hand, textual explanations must follow the logic of the text and can only introduce aspects one at a time¹⁰. While the more analog nature of simulations may not necessarily provide any objectively right answer, it allows for students to systematically rule out wrong answers through a trial-by-fire approach. This leaves them with a much more multidimensional understanding of the problem that simple memorization of a predetermined "right" answer does not offer. It promotes the ability to think algorithmically, in cognitive *if-then* loops pertaining to recognition of scenarios they experiences through simulation.

Even more importantly, through this process, students can test the boundaries of where theory fails and becomes unpredictable. This ability to experience unforeseen problems provides conceivably the most practical knowledge of a system⁸. Ultimately, observing such rare events makes the difference between a student who is prepared to handle variability in actual practice and one who is not³.

All of the instantaneous feedback and creative trial-and-error experience that students get from simulations ultimately serves to create an emotional connection to the lesson. In the long run, a student who does not care for a subject will not learn; so, making students feel an emotional engagement is key²⁸. Such engagement can arise as a

result of the goals, challenges and storylines that simulations entail; they make lessons multidimensional and thereby more interesting⁸. For example, the challenge posed in mock trading competitions engages students, as they are forced to develop their own strategies and apply lessons that they have learned. This is reminiscent of the creative trial-and-error mentioned above, which can motivate students to keep trying new solutions. Motivation is conceivably a prerequisite for engagement, and so an emotional connection with a simulated lesson will continue to feed upon itself⁸. Instantaneous feedback allows this constructive cycle to keep going, keeping students from losing focus before the results of their last speculative effort are returned to them. Thereby, the instantaneous feedback provided by simulations inspires creative experimentation, which leads to greater engagement and abstract understanding¹⁹.

The use of simulations, however, can have some significant drawbacks that must be taken into consideration. Chief among these drawbacks is the time needed to design an effective simulation-based lesson that feeds off of the requirement that simulations accurately replicate reality²⁰. All simulations are subject to a basis of assumptions about reality upon which they operate; assumptions create critical breakpoints where the simulation can deviate from the real world, so designers must spend time to minimize these assumptions.

Additionally, the simulated agents that with which students interact derive their behavior from algorithms assigned to them. Should these algorithms be too predictable,

the simulation's realistic touch would be lost, so ample time must be allocated to designing non-transparent behavior algorithms for simulated agents.

Effective simulations also need data sufficient in terms of both amount and applicability, which could pose difficulties in terms of the time needed to find data and the inconvenience of renewing data when needed²⁰. Beyond just the creation of the simulation itself, simulations may inspire Hawthorne effects and stress of judgment in an ill-designed educational setting²⁷.

Finally, there are the technical limitations that simulations entail, which can range from non-ergonomic simulation design to issues with proprietary software⁸. Specifically, simulation-based lessons can require significantly more time than traditional lessons since the students must be first taught how to use the simulation and any related hardware before any other teaching can occur²⁷. Nevertheless, these costs can decrease as society becomes more accustomed to technology, so the benefits of simulation-based education can still outweigh the costs.

There are four major attributes that define what constitutes a good educational simulation. Although this list may not be entirely comprehensive, it begins to cover the critical characteristics of beneficial simulations.

First, a good simulation is realistic. The algorithms that drive the behavior of simulated agents must be rich and complex, replicating the intricacy of human thought

and forcing the student to interpret the behavior more extensively. Designers can bypass this worry by demonstrating that the simulation can yield the same results as seen in actual specific historical occurrences.

Second, a good simulation is original. A simulation only has value if it offers a new perspective on an issue and forces students to think about something in a different way, drawing their attention to the particular aspect of an issue that the instructor wishes to examine⁷.

Third, a good simulation is interactive. Students learn more effectively when they actively participate in visualizations, altering inputs and testing scenarios²². An interactive simulation will grant flexibility throughout this process, allowing students to construct and promptly deconstruct ideas to progress towards a comprehensive understanding of the material¹⁹.

Finally, a good simulation guides the student. Gagne and Brown⁹ find that guided discovery leads to greater retention than unguided discovery. Thereby, a simulation-based lesson must lay a path for students to follow in order to keep them from getting caught up in unrelated aspects of the program.

Figure 1. The Lewinian Experiential Learning Model

These beneficial simulations can target two main methods of education, defined here as “application-based” and “outcome-based” education. Because the use of simulations focuses the students’ attention on experiential, “here-and-now” learning, both methods can easily be mapped out on the Lewinian experiential learning model illustrated in Figure 1, which divides the learning process into 4 sub-processes: observations and reflections, formation of abstract concepts, testing concepts, and concrete experience¹⁹.

The first method, application-based education, uses simulations as a tool to reinforce theory taught by the instructor. For example, once a class has been taught that increasing supply lowers cost, a simulation can give students the chance to experience the trend for themselves. Students first learn theory and then get the chance to apply it, so the second step of the Lewinian cycle is presented *a priori* and simulations cover the testing concepts and concrete experience phases.

The second method, outcome-based education, uses simulations as an environment where students derive their own abstract conceptualizations from observations¹⁷. Instructors may then massage these observed trends to reveal the

underlying theory. To continue the example above, students would first experience the behavior of prices with differing levels of supply, form the idea that price goes down with increased supply, and have their theories reaffirmed by the instructor through group review. This method utilizes simulations more extensively in the experiential process, as students undergo the entirety of the Lewinian cycle at least once through simulation. For this reason, the experiment utilized in Section IV uses an outcome-based model of learning to test the efficacy of simulation-based education.

Section 4: Experiment

Objectives

In order to test the hypothesis that simulation-based education is more effective than lecture-based education when teaching market microstructure, an experiment was developed that could impartially and directly compare the two approaches. The main objective was to test the efficacy of simulations in education relative to traditional lectures. Some important sub-objectives included: adding to the body of knowledge expressly in the field of microstructure, specific testing of deep content learning, and determining other qualitative differences between the two approaches.

Design

In many papers advocating simulation-based education, experiments are designed such that only the simulation itself is tested. As a result, only limited qualitative results of its educational value are recorded through surveys of student satisfaction⁸. Because the

main objective of this experiment was to directly compare conceptual and theoretical learning, it was necessary that the subject population be split into two groups: one experimenting with a simulation and the other receiving information in a lecture-based format. In order to attain quantitative results, both groups were given the same pretests and posttests. The pretest and posttest covered the same material and were graded by the same individual to avoid bias. These tests included questions to test subject matter knowledge and self-assessment questions to gauge the students' levels of comfort with the topic.

Methodology

The experiment was conducted using a sample of 18 masters students enrolled in a financial engineering program. The students were first given a pretest to complete. This had self-assessment questions where students were asked to rate their own knowledge on topics such as electronic markets and securities trading on a Likert scale from 1 to 5 as well as a few factual subject matter questions to gauge baseline knowledge. These questions were designed to force the student to apply concepts, judging how much of a grasp the student has on the material. Then, all the students were given a 15-minute presentation introducing the concept of markets and market liquidity and the different types of traders that would be covered in the rest of the lesson.

Next, the students were divided into two groups: Lecture and Simulation. The Simulation group included 10 students, and the Lecture group included 8 students. The Lecture Group was given a continuation of the original lecture describing the objectives

and effects of different traders on markets and liquidity followed by a number of practice problems that the group reviewed as a whole. Overall, this took about 30 minutes. The Simulation Group was given a parallel lesson covering the exact same points, except it utilized a trading simulation program shown in Figure 2^{13 25}. This took about 50 minutes.

Figure 2. The simulation used in the experiment.

The simulation program used replicated a futures market where students could manually set the number of different types of traders participating in the market and then observe how that affected the speed, amount, and style of trading. The Simulation group was given a lesson plan with guiding questions to follow. Answers to the questions, which were recorded by the same lecturer to maintain consistency, were also provided. Finally, both groups were administered the same posttest as shown in Appendix B. This included the same self-evaluation questions as the pretest to allow for direct comparison,

as well as a number of different application questions to quantitatively compare the lecture-based and simulation-based methods.

Results

Overall, the Simulation group took about 20 minutes longer to complete the lesson but scored higher on the posttest and reported they were more confident in their knowledge than the lecture group. The Simulation group had a mean score of 2.35 and a median of 2.25 out of 5, while the Lecture group had a mean score of 2.0625 and a median of 1.75. Since a Likert scale was used, intervals between scores were not explicitly defined, and, therefore, the mean was determined to not be a properly indicative measure. Unfortunately, due to the small sample size, these results were not statistically significant; a larger experiment could yield more conclusive data as to the value of this style of teaching.

For the self-assessment questions, the Simulation group started with an overall median and mode of 3 out of 5 for all 7 questions on the pretest, and ended with an overall median and mode of 4 out of 5 on the posttest. On the other hand, the lecture group started with an overall median and mode of 4 and ended with an overall median of 4 and a mode of 3. This result is interesting because it suggests that the simulation not only made students in that group more comfortable in their knowledge, but it also indicates that the students taught using a lecture-based approach reported they were slightly less comfortable with the subject material. This could have noticeable implications for teaching methods not only in microstructure but in all fields. Once again,

the small sample size forces a lower level of confidence, hindering the power of the conclusion, but this signifies a possible trend that future work with larger groups could portray more conclusively.

Section 5: Conclusion

Due to its various attributes, concept-focused education, powered by simulation, provides a better alternative to theory-focused education, which relies on symbolic equations and brute memorization. Simulations allow for a comprehensive viewing of a system, thereby allowing students to gain experiential knowledge operating in the system with most of its intricacies and imperfections. This has already been recognized in many fields of study, namely medicine, and so simulation-based education is on the rise. The deep-content knowledge that it offers would aid in the development of more experienced and able future citizens³.

The results of the experiment conducted show that simulation-based education could be a more effective method of teaching complex financial topics such as market microstructure. Although no conclusive statements can be made, trends show that simulation aids both in students' grasp on complicated material as well as their confidence in their grasp on the material. At the cost of taking more time, simulations can be used in teaching strategies to ensure that students attain a holistic understanding of financial systems and leave class less confused than when they entered. Especially with topics like market liquidity and trader impact, which tend to have a number of moving

parts, the ability to play with scenarios and visualize cause-and-effect chains seems to have a positive effect on student comprehension. Confusion in these areas can help precipitate damaging market crashes such as the Flash Crash¹⁸ ; so, a sound, long term risk mitigation step would be improvement in the quality of financial engineering education for the next generation of traders and regulators, particularly in the area of market microstructure, .

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Appendix A:

The pretest used in the experiment

Pretest

1. Rahim has 100,000 shares of oil futures that he would like to sell. He contacts his friend Abdul, who just happens to be a block trader. Abdul sells off Rahim's shares, and the market price of oil futures does not drop noticeably. Does this show liquidity in the market? Why or why not?
2. Harold is an avid collector of Pez dispensers. The National Pez Showcase is coming up, and Harold is desperately looking for a vintage Mickey Mouse dispenser to show off. Is Harold supplying, demanding, or not changing liquidity in the market for vintage Mickey Mouse Pez dispensers?
3. Armando firmly believes that the price of Julio Iglesias records is going to rise soon and is very eager to buy. Ishaan, on the other hand, found some Julio Iglesias records sitting in his attic the other day and is looking to get rid of them. However, they do not find each other, so Ishaan is left with his dusty records

while Armando feels disheartened. How would an intermediary have helped in this situation and how would that affect liquidity?

On a scale of 1 – 5, with 1 meaning “least knowledgeable” and 5 meaning “highly knowledgeable,” how knowledgeable do you consider yourself to be on the following topics regarding financial markets? Circle the appropriate number.

4. Securities:

1 ----- 2 ----- 3 ----- 4 ----- 5

5. Electronic trading exchanges:

1 ----- 2 ----- 3 ----- 4 ----- 5

6. Market liquidity:

1 ----- 2 ----- 3 ----- 4 ----- 5

7. Bid-ask spreads:

1 ----- 2 ----- 3 ----- 4 ----- 5

8. The bilateral search problem:

1 ----- 2 ----- 3 ----- 4 ----- 5

9. Different types of traders:

1 ----- 2 ----- 3 ----- 4 ----- 5

10. The effect of different types of traders on liquidity:

1 ----- 2 ----- 3 ----- 4 ----- 5

Appendix B:

The posttest used in the experiment

Posttest

1. Gandalf is a fundamental buyer of magic staffs. He is looking to buy, but it just so happens that today the National Union of Market Makers decided to strike. How are his chances of finding a good deal on a staff?
2. Sam is watching the price for a specific market that started the day at \$20, and he notices that although the market price moves around significantly, it always seem to move back to \$20. What could this imply? What type of traders may have caused this?
3. Will the market with the order book below have a high or low order flow (number of trades actually being executed)? Explain how the bilateral search process ties into your answer.

4. Abdul has done research on a certain stock and is sure that it's true value is above the current market price. He tries to convince Jamie, a pre-committed buyer, to trade with him at a higher price. Would Jamie shift his price? Explain how traders like Jamie affect the market.

5. Jack is looking to buy 10,000 shares of a certain stock quickly. Who would he most likely trade with, and where on the bid-ask spread would his trade fall?

On a scale of 1 – 5, with 1 meaning “least knowledgeable” and 5 meaning “highly knowledgeable,” how knowledgeable do you consider yourself to be on the following topics regarding financial markets? Circle the appropriate number.

6. Securities:

1 ----- 2 ----- 3 ----- 4 ----- 5

7. Electronic trading exchanges:

1 ----- 2 ----- 3 ----- 4 ----- 5

8. Market liquidity:

1 ----- 2 ----- 3 ----- 4 ----- 5

9. Bid-ask spreads:

1 ----- 2 ----- 3 ----- 4 ----- 5

10. The bilateral search problem:

1 ----- 2 ----- 3 ----- 4 ----- 5

11. Different types of traders:

1 ----- 2 ----- 3 ----- 4 ----- 5

12. The effect of different types of traders on liquidity:

1 ----- 2 ----- 3 ----- 4 ----- 5

Thank you for participating!