# Applying entrepreneurial teaching methods to advanced technical STEM courses

## *Data-X as a Framework for Introducing Innovation Behaviour into Applied Technical Subjects*

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***Abstract*—A vast majority of Science, Technology, Engineering, Mathematics (STEM) courses and pedagogical frameworks concentrate on teaching the fundamental concepts and theoretical underpinnings of the tools related to the subject. While this aspect is important, we recognize that the teaching methods in a majority of the STEM courses today are broken; there is a major discrepancy between the skills and mindsets in technical classes and the ones that are useful to solve actual problems in "the real world". Therefore, we suggest a new teaching framework called Data-X where entrepreneurial teaching methods developed in the Berkeley Method of Entrepreneurship are applied to advanced technical topics. Through inductive learning and by practicing story creation, stakeholder generation, adaptation, ideation, innovation processes, and by having a diverse mix of students being coached by a network of expert advisors, this highly applied teaching method empowers students to pursue and find solutions to open-ended projects and problems. The Data-X framework has been implemented and tested for three semesters in a UC Berkeley course called Applied Data Science for Venture Applications. In the class the students pick up, become comfortable, and utilize state-of-the-art tools in Data Science, Machine Learning, and Artificial Intelligence. The results, feedback, and testimonials we have received upon offering the class have been overwhelmingly positive, and we propose that the ideas and concepts behind Data-X can help fix many problems in modern STEM education.**

***Keywords: data science; pedagogical frameworks; teaching methods; entrepreneurial mindsets; machine learning; STEM education; innovation processes; inductive learning***

## I. Introduction

Recently there has been an increased interest in educational methods used at universities. At the recent international leadership meeting in Davos, organized by the World Economic Forum and attended by presidents, prime ministers and executives, the future of education was on the agenda [10].

> "If we do not change the way we teach, 30 years from now, we are going to be in trouble. The knowledge-based approach of '200 years ago' would fail our kids, who will no longer be able to compete with machines. Children should be taught soft skills, independent thinking, values and team-work... Only by changing the way we teach, our children can compete against machines" said Jack Ma, founder of the Chinese e-commerce giant Alibaba Group [10].

Hence, the question is not IF we should teach, or WHAT we should teach, but rather HOW we should teach.

Education will always be important and play a vital role for economic growth and the well-being of society and its individuals. Advanced technical courses, such as STEM (Science, Technology, Engineering, Mathematics) will continue to be important in the future. The need for people in the workforce with an understanding of STEM is projected to grow almost two times faster than the average of all occupations; employment in all occupations is projected to grow with 10%, whereas the corresponding number for employment in STEM occupations is projected to grow at a rate of 19% [1], [2]. Entrepreneurship is an important component in this expansion, as it introduces the capability of translating Science, Technology, Engineering and Mathematical (STEM) understanding into useful innovations. The economic engine over time has, in the US and other countries, been technology [3]. Clearly, giving students a good understanding of STEM subjects is important for our society.

The question remaining is HOW the STEM teaching should be done? How can we move away from teaching knowledge that is solely information based and instead enhance the learning of skills, values, mindsets, and team-work?

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This paper describes how an advanced technical STEM course, that by default should have been traditional in its setup, instead can be made much more relevant and appropriate for today's students and today's industrial challenges by applying a mindset-focused pedagogical approach originally designed for entrepreneurship. The Data-X framework is designed to teach and explain advanced STEM topics while at the same time integrating the pedagogical methods of the Berkeley Method of Entrepreneurship, as illustrated in Fig 1. The course teaches a STEM subject by enhancing the importance of skills, values, mindsets, and teamwork, hence, making it a course in line with the Davos' vision for the future of education.

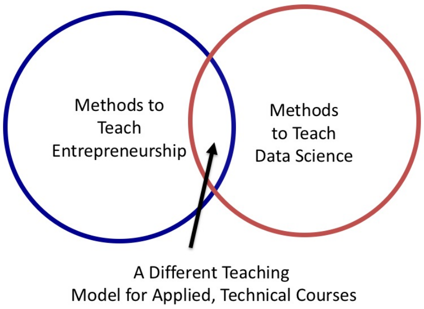


*FIGURE 1: This paper is about the Data-X framework, which mixes methods from deep technical fields with methods for entrepreneurship courses*

This paper starts with an introduction to teaching and learning in general (section 2), thereafter follows a description of the Berkeley Method of Entrepreneurship (BMoE) (section 2). Thereafter, it describes the Data-X framework and course (section 3) including a brief description of the knowledge domain that the course covers (section 3a), and a presentation of how the course copes with soft skills such as independent thinking, values/mindsets, and team-work (section 3b). After that, results, proof-of-concepts, statements from students and industry-mentors are presented (section 4). Finally, the conclusions related to this teaching method and its results are presented (section 5).

## II. TEACHING AND LEARNING

Generally speaking, teaching is interpreted as the act of helping someone to learn. In recent years, the discussions about teaching have shifted from "how to present and transfer knowledge from a teacher to someone else" to "how information and knowledge provided is perceived by the receiver" [4], i.e. from a teacher-student-transfer focus in which the subject is only the transported goods, to the student-subject-relation focus in which the teacher is only the medium used. The task for the teachers is to help the students to learn. This shift is illustrated in the didactic triangle, see Fig 2, [6].

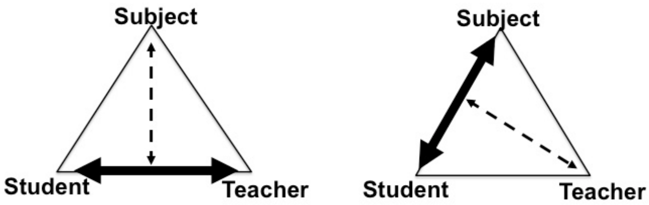


***FIGURE 2: An interpretation of the Didactic Triangle showing a shift from the teacher-student-transfer focus (left) to the student-subject-relation focus (right).***

The teacher-student-transfer focus (left in Figure 1) is also referred to as deductive teaching, whereas the student-subject-relation focus (right in Figure 1) is referred to as inductive learning [5].

- Deductive: In a deductive classroom, the teacher conducts lessons by introducing and explaining concepts to students, and then expecting students to complete tasks to practice the concepts. The students should demonstrate that they have understood the concepts by repeating what the teacher just told or did.
- Inductive: In an inductive classroom, the teacher presents or exposes the students to examples that show how the concept is used. The intent is for students to "notice", by reflecting around the examples, how the concept works. The students should demonstrate that they have understood by re-inventing the concepts based on their own experience.

Deductive teaching methods are suitable to use in subjects where facts and raw knowledge is of most importance, whereas an inductive teaching approach is suitable to use when skills, experience and values are in focus and can be applied to solving real-world problems. In the new era of education, and according to the Davos discussions [10], inductive teaching approaches will become more important [9].

## III. BERKELEY METHOD OF ENTREPRENEURSHIP

A novel teaching and learning approach, referred to as the Berkeley Method of Entrepreneurship (BMoE), has been developed at UC Berkeley by local and visiting researchers [7]. BMoE is focused around learning rather than teaching, compare Fig 2, and the students are pushed to proactively develop their own understanding rather than waiting for someone to teach them what they need to know. The students are trained to frame problems and find ways to solve them and then reflect on what they have learned from the process. BMoE is based on the following five (5) principles:

- Students are learning by doing [11].
- Instructors host the environment for students to interact directly with the problem. Students make their own decisions and learn inductively [5].

- Behavior training for students is done through games and exercises [12].
- Learning outcomes prosper when focusing on goals and processes instead of grades.
- Learning leverages on mimicking real-world entrepreneurial situations [13].

Hence, according to BMoE, the students benefit from extending their theoretical and practical understanding of entrepreneurship, with an understanding of the entrepreneurial mindset [14]. Generally, the mindset is a way of thinking which influences the way someone sees and acts in a situation; the mindset is reflected in the person's behavioral patterns. BMoE stresses the importance of explicitly including mindset in the entrepreneurship education according to the MIND-methodology [8], see Fig 3.

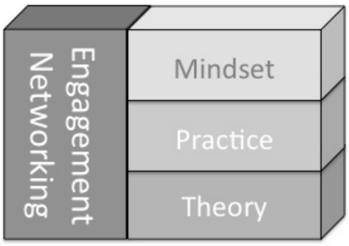


***FIGURE 3: The four building blocks of MIND-methodology.***

### *A. Behavior and mindset in BMoE*

Ten behaviors of entrepreneurs have been identified as important cornerstones in having a thriving entrepreneurial culture [7]; examples include storytelling, appreciating collaborations, and understanding the value of diversity, etc. Another behavior is the willingness of existing entrepreneurs as acting role-models. Identifying oneself with a role-model is the first step on the journey of becoming an entrepreneur, hence engaging in networks becomes essential and is included in BMoE.

### *B. Games and debriefing sessions*

BMoE includes behavioral training as well as reflections on mindset. For this, an inductive game-based teaching approach is used together with debriefing sessions. Various games, referred to as the BMoE-games, have been developed [15]. A game can be defined as a structured playing, usually undertaken for enjoyment and sometimes used as an educational tool. The idea is to let the games invoke a certain behavior or mindset of the student. After the game, the students should reflect about his/her own behavior and compare it with that of successful entrepreneurs. Debriefing sessions and learning journals are powerful learning tools [16]. The result of the reflection can be either an ignition for the student (confirming that he/she wants to become an entrepreneur), an extinguisher (confirming that the student does not want to be an entrepreneur) or a wake-up call (the student realizes they need to develop specific mindsets).

## IV. DATA-X COURSE

Based on this background, we have laid the groundwork for extending the approaches of the Berkeley Method of Entrepreneurship to specifically be applied to more technical disciplines within STEM education, particularly the fields of data science, machine learning, and artificial intelligence. We believe this will result in new and better approaches to teach highly applied concepts in STEM education. The title we have given this pedagogical framework is "Data-X". We consider the title to be broad enough to encompass, not only data science and algorithms, but also digital transformations, emerging and broader technologies, applications, as well as innovation in general.

In this direction and with this goal in mind we designed and implemented a proof-of-concept of the Data-X framework in the form of a graduate and upper-division undergraduate course at UC Berkeley within the department of Industrial Engineering and Operations Research. The course has been offered for three consecutive semesters (Spring 2017, Fall 2017, and Spring 2018) under the formal course title '*IEOR 135 / 290: Applied Data Science with Venture Applications*'.

In this semester-long course version of Data-X, we have combined BMoE approaches to include narrative generation, open ended challenges, project adaptation, self-reflection, teamwork skills, ecosystem and stakeholder generation, and other innovation behaviors and mindsets into this highly technical field, without reducing the technical intensity and applicability of the course. Our approach may also be considered a combination of design and maker philosophy, combined with traditional systems perspective of data science (in contrast to a pure algorithmic focus).

The web site of the course, see Fig 4, contains the class syllabus, the teaching material, the advisor network, code samples, project descriptions and more.

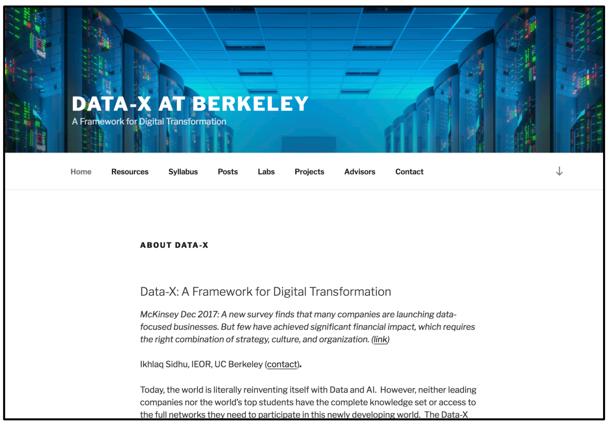

*FIGURE 4: The www.data-x.blog web site.*

## V. Data-X course vs traditional courses

The Data-X approach addresses the issue of traditionally narrow perspectives in data science and other technical STEM courses. The narrow perspective found in many courses today needs to be changed into a holistic approach, since it better mimics the challenges students will be faced with when leaving academia and entering the workforce.

### *A. Lack of holistic nature*

Often in technical domains and STEM education, there is a tendency to teach each portion of a subject or specialization siloed as separate components. Instead of becoming familiar with how their knowledge can be applied in the real world, students learn concepts in disparate blocks of specific topics that almost never are assembled (and if they are combined, e.g. in a class project, then it's almost always a cookie cutter problem designed for the purpose of fitting the class material and it is not actually related to how an actual problem would be framed).

We would like to illustrate this with an example: Imagine that we would like to teach golf over four years (the equivalent of an undergraduate degree at universities in the US). Instead of allowing our students to play golf and try different approaches, techniques and strategies in golfing, we would instead only teach students how to correctly place a golf ball on the ground in the first year, and then in the second year all classes went over the theoretical concepts of different swings, and so on for the next 2 years. In this setting a student could literally graduate without ever having played golf.

In the Data-X model, every student has to pursue an open-ended project that brings a holistic nature to the course, allowing students to implement a fully working system from a high-level story narrative. The projects act as a real-world training scenario where student-teams apply their taught skills to actual problem solving, and they get to experience the process of weaving all their obtained knowledge to create a fully functioning system. They do this from the beginning of the course, not after extended periods of practice. Students work in teams of 4-5 on projects, enabling the experiential development of soft-skills like planning, collaboration, collective decision making etc. The Data-X framework essentially empowers students to understand, form, and work with applied innovation strategies, by making them see and understand the holistic view of how to use cross-curricular knowledge for problem solving in real-world situations.

### *B. Use of Tools vs Creation of Tools*

Most data science courses today focus on teaching the students how to understand and re-create implementations of standard algorithms. A lot of time is spent on explaining the in-depth theoretical concepts of how these algorithms work. Usually, little or no time is spent applying these tools to solve actual real-world, open-ended problems. For example, a common assignment might be to write the code for the stochastic gradient descent algorithm, even though this function could be called and implemented in one line of code from a library. Much less emphasis is placed on putting all the tools and solutions in the context of a system's view. It is essential to teach the implementation of a larger, full-scale system using optimized and available data science tools, an experience that we argue is much closer to how professionals in these fields are working.

For this reason, Data-X introduces students to the state of the art, open source Machine Learning stack. This is the stack that is commonly used by ventures and technology firms today and includes Tensorflow, Scikit-learn, NumPy, SciPy, SQL, Pandas, NLTK, Spark and other libraries created for the Python programming language.

### *C. Connecting Technical Detail with Mindset and Behavior*

Data-X is not only intended to teach the state of the art processes, methods, and tools for solving data problems, but it allows students to apply and experience these tools and methods while finding solutions to their project problems in an actual innovation process.

To promote the mindset and psychology of innovation we introduce the students to participate in a creative process cast in the framework of the subject. Contrary to regular data science practice, our process does not have students coding on the project at the beginning of the course. Instead, the first four weeks are spent developing a story and a narrative around the project idea, in what we call a *low-tech demo* of what they intend to develop. The low-tech demo is essentially a presentation where the students utilize a slideshow and a 15min verbal presentation to outline the project's objective, requirements, user interface, main technical components, and risk levels of each of the yet unlearned tasks. An agile development process follows this, where teams start working on their solutions. The actual implementation process is full of unknowns, directional deviations, and self-learning experiences that can extend beyond the material of the course. Self-reflection for inductive learning is integrated within the course as the students can pursue any open-ended project of their choice, while being guided and receiving feedback from experts in our mentor network. This process supports team development as much as it does technical direction.

In parallel with the project, the course offers lectures in mathematical theory, computer science topics, and data science / machine learning algorithms and code samples throughout the course, see Fig 5.

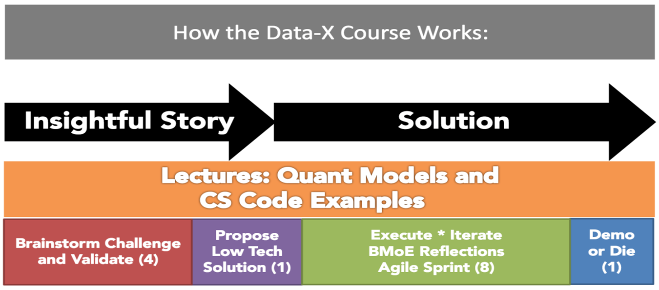


***FIGURE 5: Course elements include a project narrative, low-tech demo, and agile development with theory and code samples.***

## VI. *Behavior and Mindset in the Data-X course*

BMoE, originally designed for teaching and learning entrepreneurship and innovation, has a strong student-centric and mindset-focused approach. Several of these aspects are also addressed in the Data-X framework.

### *A. Implementation Requires Story Narrative*

From BMoE and other entrepreneurship courses, we are aware that new ventures and new initiatives start from story narratives that are constructed to gather and interest stakeholders. In Data-X, we have implemented the development of the insightful story into the pre-work of the project. The story narrative is used both to form teams as well as to communicate the low-tech demo of the project ideas.

### *B. Learning from the Problem / Challenge*

Another hallmark feature of the BMoE is that students learn from solving actual problems, and not only from the instructor. The alternative over-constrains the learning content, reduces inductive learning, and limits creativity.

In Data-X, the instructor is not always the medium of communication, primarily by making the project very open ended. In fact, the scope of the project is even allowed to be outside of the scope of the teaching material. This enables students to explore and acquaint themselves with new and powerful tools that can be self-learned. For example, advances in UI design or blockchain may be brought into the project, even though these subjects are not specifically addressed in any lecture nor listed on the syllabus.

### *C. System Architecture (breadth) vs Algorithm (depth)*

The Data-X framework does not focus on the in-depth details of all the components of data science and STEM education, e.g., the theoretical foundations of algorithms, but in the breadth of the system architecture. As part of the low-tech demo, a high-level system architecture design must be presented. This forces the students to think about and evaluate different solutions to their problem in a holistic process and they need to understand which components that have to connect, in order to build a functioning system.

### *D. Behavior: Adaptation and Agility in the midst of Planning*

To reinforce the actual process of innovation the Data-X model allows adaption and agility in the project development process. Week to week re-prioritization of work allow the project to adapt to moving targets and changing requirements which is an implicit part of real life innovation. Many projects also arrive at the conclusion that their proposed solution might be infeasible, in that case we allow the groups to pivot and seek out a totally different problem to solve.

### *E. Self-Reflection and Inductive Learning*

Students are encouraged to keep a log of what has gone well and where the project did not go well. This is a fundamental technique in inductive learning to increase self-awareness. The scope of reflection covers teamwork, technical issues, and strategic decisions such as what tool would be most effective in what situation.

### *F. Collaboration and Team Diversity*

Another key element of BMoE behaviors is the development of diverse teams. Teams which have large commonality have very little information to trade with each other. In the technical Data-X parallel, during team formation, students are encouraged to discuss what skills and strengths they would bring to a potential project. Whether it might be specific coding skills, an idea, knowledge of the application, a sense for aesthetics, or other capabilities to increase the intellectual diversity of the team. In the UC Berkeley class we also have students coming from a diverse background of majors, such as computer science, mathematics, statistics, business, cognitive science, humanities etc.

### *G. Effectiveness and Resource Allocation over Precisions*

Projects from this course have simply amazing outcomes (papers, ventures, social impact, etc.) as described in the results section. However, to accomplish this in only 8 weeks tradeoffs will have to be made. To learn how to effectively allocate resources and what to leave in an imperfect form for the holistic good of the entire project is an innovation skill that has been articulated as a BMoE behavior. In Data-X, we allow this time pressure to actually promote good decision-making and to learn how to balance desire for perfection with effectiveness in this resource allocation process.

### *H. Network Engagement*

No entrepreneurship course is complete without network engagement and development of an ecosystem consisting of mentors, investors, and other supportive stakeholders. In the Data-X model, we have developed and integrated an ecosystem of academics, executives, technical leaders, start-up CEOs, and investors in data related industries. These experts actively mentor, advise, and guide the student groups in the work on their projects in accordance with the need of the students. The diversity of the network is an essential component as no single segment of the mentor / advisor community has a complete overview of the data science field. Venture people often have insight into opportunity areas and industry segments, large firm executives understand where larger scale problems get stuck and how to compete with effective processes etc. Each segment has a viewpoint to offer. Providing a network is another key ingredient to an effective applied and technical course that we have learned from our experiences teaching entrepreneurship and in developing the BMoE behaviors.

## VII. Results, Outcomes and Proof-of-concepts

We spent a year to develop the course materials, lectures, code samples, and the mentor network, and at the time of writing we have offered the course two times and we have just embarked on our third semester. We have seen very promising results when implementing and offering the Data-X teaching method in the following manner:

*a)* Increasing enrollement figures, with an approximate increase of 100% over the semesters the class has been offered, only by utilizing word of mouth advertising. We are now in the third semester of the course, IEOR 135 / 290 Applied Data Science with Venture Applications, and we continue to see semester over semester growth in student interest.

*b)* High level proficiency of projects within only 3 months. Students are able to develop projects that do everything from improving state of the art models predicting asset prices to automatically categorising garbage for recycling. Student teams worked on projects where they created a new use case for Blockchain in Healthcare, developed algorithms to detect cartilage damages, created an application to enable safe commute for pedestrians, created a working model to classify nanometer material thickness from 2D images, created sales chatbots, created applications to automate the filling of performance reports for the military etc. Our various projects received offers for venture backing and many teams have submitted their analysis and findings for publishing.

*c)* A small subset of positive feedback and testimonials:

*"I feel like I'm really learning how powerful data science tools can be. When we were brainstorming project ideas, I didn't think any of the ideas were feasible. However, with each week, I'm learning how pre-existing libraries and tools can be easily used and combined to create really powerful products."*

*"Sidhu's class is great because he shows you all the cool things that people are doing with data science and the goal is not really for you to understand 100% of the material like we traditionally do in Berkeley classes, but to understand as much as you can and try to contextualize it. You don't have to be an expert to take this class but you will learn a lot of it."*

*"I think this class is so awesome because it teaches the tools and concepts that are most commonly used in workplace teams that are involved with data science and applied machine learning. The vast majority of company teams that I've applied to within the past year use the tools taught in this class. When I arrived at my data science internship this summer, I already knew how to use most of my team's stack."*

*d)* Relevant research output for graduate students. Many graduate students that take this course do not have a computer science background, but instead they are from other areas such as bioengineering, material science, etc. They are able to form cross-disciplinary teams with computer science and other undergradaute students. The net effect is that these new data science tools can be leveraged in the graduate student's research to produce results that e.g. can create automated processes of data collection and analysis techniques in their respective fields. Many projects we have hosted have started to influence research in other academic areas.

*e) Finally, we have been able to develop an early community. The community includes mentors from industry and new ventures, current and past students, as well as academic experts. This community allows cross-recuiting for both ventures, larger firms and universities.*

## VIII. Conclusion

Data-X as a teaching framework aims to close the gap between STEM education and how the methods, tools, and concepts in data science and machine learning are applied when solving actual, open-ended problems. Data-X is built upon the Berkeley Method of Entrepreneurship to incorporate inductive learning and innovation behavior into the teaching methods of a highly technical topic. This prepares the students for situations they will face when entering the "real world" after graduation. Together with our extended network of expert mentors and advisors we have created an ecosystem and environment where the students are able to solve novel problems, start new ventures, and publish research – after working on a problem of their choice for just one semester.

We believe that the current educational system brings a lot of value to students, however as we pointed out in our golfing analogy (section 5c): To become a good golfer you cannot only learn about the concepts of golfing, you actually have to play golf also. Through the Data-X framework we teach the students the concepts of data Science, and more importantly, we also let them make use of the tools and concepts to solve actual problems.

The results, feedback, and testimonials we have received upon offering the course have been overwhelmingly positive and we believe that the ideas and concepts behind the Data-X framework can help driving the future of STEM education in the right direction.

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