From Teaching System Dynamics towards Total Immersion in Advanced Model-Based Policy Analysis

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Abstract: *In this paper, we discuss (i) important lessons related to the latest innovations in our case-based blended System Dynamics education, and (ii) the redesign of a masters programs in which System Dynamics plays an important role. Instead of teaching System Dynamics 101, supervising System Dynamics projects, teaching Advanced System Dynamics, and supervising System Dynamics theses, we will from 2016 on rapidly ramp up the level from basic to intermediate System Dynamics with intensive workshops, teach students the most advanced methods and techniques, integrate System Dynamics with other methods and analytical approaches, and embed our Master thesis students as much as possible in real modelling and simulation projects and research teams. The envisaged changes are expected to enable us to transition from introducing engineers to model-based policy analysis to training the best model-based policy analysts.*

"Most of the challenging issues faced by society today cannot be solved by technology alone. Engineering excellence must be coupled with insight into societal needs and the mastery of project and process management tools" (EPA 2013)

1. Introduction

The aim of TU Delft's master program in Engineering and Policy Analysis (EPA) is to train technical students to become strategic advisors in complex societal, technical and political contexts. Model-based policy analysis is an important aspect of this master program. The level at which these model-based policy analytical skills are taught in this program needs to be raised tough. The issues dealt with today and in the future are getting ever more complex, uncertain, urgent, and thus challenging. Figure 1 shows a possible future of model-based policy/decision analysis in which different modelling methods are integrated with each other, with data and data science, gaming, etc.

This is a future we believe we need to prepare our students for. In order to do so, we need to redesign the EPA curriculum. The current paper focusses on some major changes in the Engineering and Policy Analysis (EPA) master program in which System Dynamics (SD) (Forrester 1961; Sterman 2000) has a prominent (mandatory) place. We also discuss the latest experiments, innovations, success stories, failures, lessons learned, and new directions in our System Dynamics teaching and testing at Delft University of Technology's faculty of Technology, Policy and Management (TPM) that enable to make some of the envisaged changes. By sharing our teaching materials the results of our teaching experiments, innovations, success stories, failures, lessons learned, and changes ahead, we believe that we can help others improve their SD education program. That is the main aim of this paper. Doing so, this paper adds to the growing body of literature on teaching and testing System Dynamics in bachelors and masters programs (Pruyt 2013a, Bosch and Cavana 2014, Pavlov et al. 2014, Davidsen et al. 2014).

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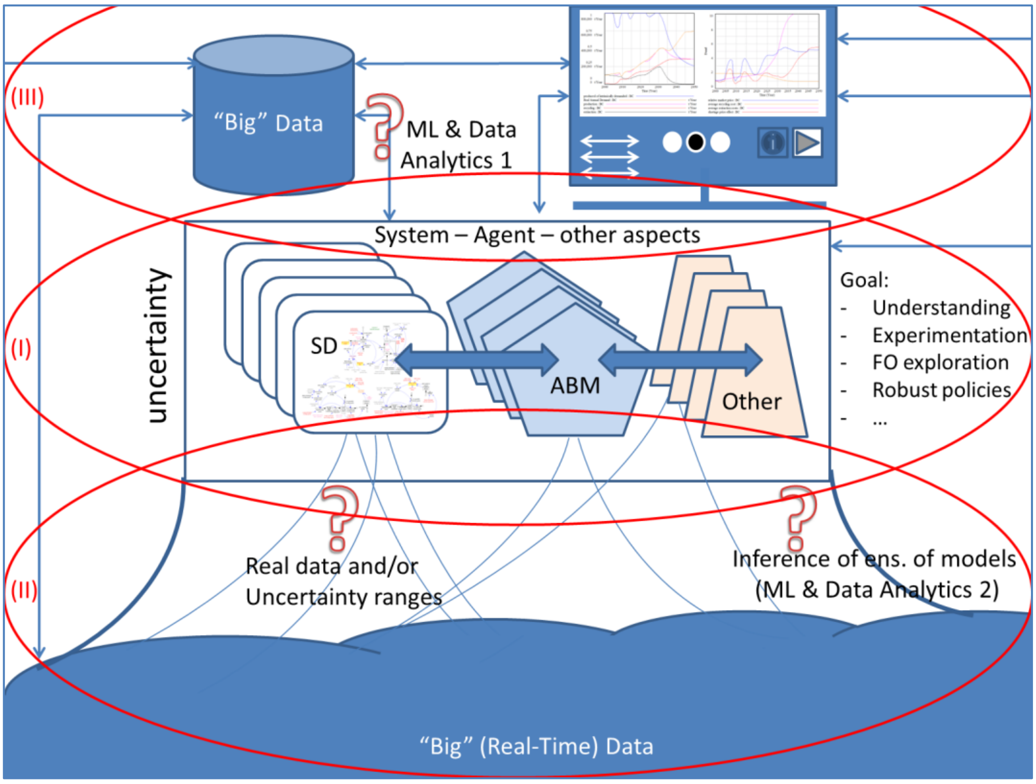

Figure 1: A possible future of model-based policy/decision analysis. Source: (Pruyt, 2015)

In this paper, we will first provide an overview of the current EPA program and SD's place in the EPA program. Then we will discuss some recent experiments, after which we will present the future EPA program and place of SD in it. Section three contains concluding remarks.

2. EPA 1.0

2.1 Why?

The core program of EPA combines systems modeling techniques, policy analytical problem structuring methods and political science courses. Systems modeling techniques are considered to be a valuable tools for these future policy analysts and consultants as they contribute to informed decision-making. We know, at the same time, that excellent modeling skills alone will not suffice as these future engineers and consultants will inevitably work in an often highly politicized, mostly international and interdisciplinary environment, which requires excellent intercultural and communication skills (Kroesen et al 2012). The program therefore aims at training policy analysts, who can communicate and cooperate and can apply a variety of analytical and modeling techniques to structure and analyze the behaviors of the multi-actor systems they analyze and study. The focus of their training is on wicked, ill-structured or complex problems in the sense that natural, technological, social, and human elements interact (Rittel and Webber, 1973). As a result, a variety of problem perceptions exists, values and interests may be conflicting, and power and resources to change things are distributed over multiple actors, who may be playing strategic games (Dunn, 1994; de Bruijn and Porter, 2004; Koppenjan and Klijn, 2004). Such multi-actor complexity is the everyday reality of analysts and problem solvers and asks for participative approaches to problem structuring by involving stakeholders in the actual conceptual modeling steps (Lei et al 2011; Enserink et al 2010; Enserink et al 2013). That is why ERPA was founded in the first place.

2.2 What?

The EPA program combines its intensive modeling courses with policy analysis courses teaching students general problem structuring techniques and stakeholder analysis techniques and uses these elements as building blocks to introduce them to the conceptual modeling of systems. We use the so-called system diagram (Sage, 1992; Sage and Olson, 2001) as a core concept to present a structured view of a problem situation. As extensively described by Lei et al (2011) the complete diagram is constructed through seven iterative steps, where each step is a sub-analysis. This structuring of an unstructured problem and defining an appropriate scope for further analysis and action are essential skills that all policy analysts should master. Hence, when developing the current Engineering and Policy Analysis curriculum we included a number of participatory modeling approaches (Shaw et al, 2006), which aim to support a diverse collection of actors in addressing problematic situations of shared concern. Moreover the conceptual modeling and systems modeling courses are supporting one another due to the overall (sequential and parallel) set-up of the program (see Figure 2).

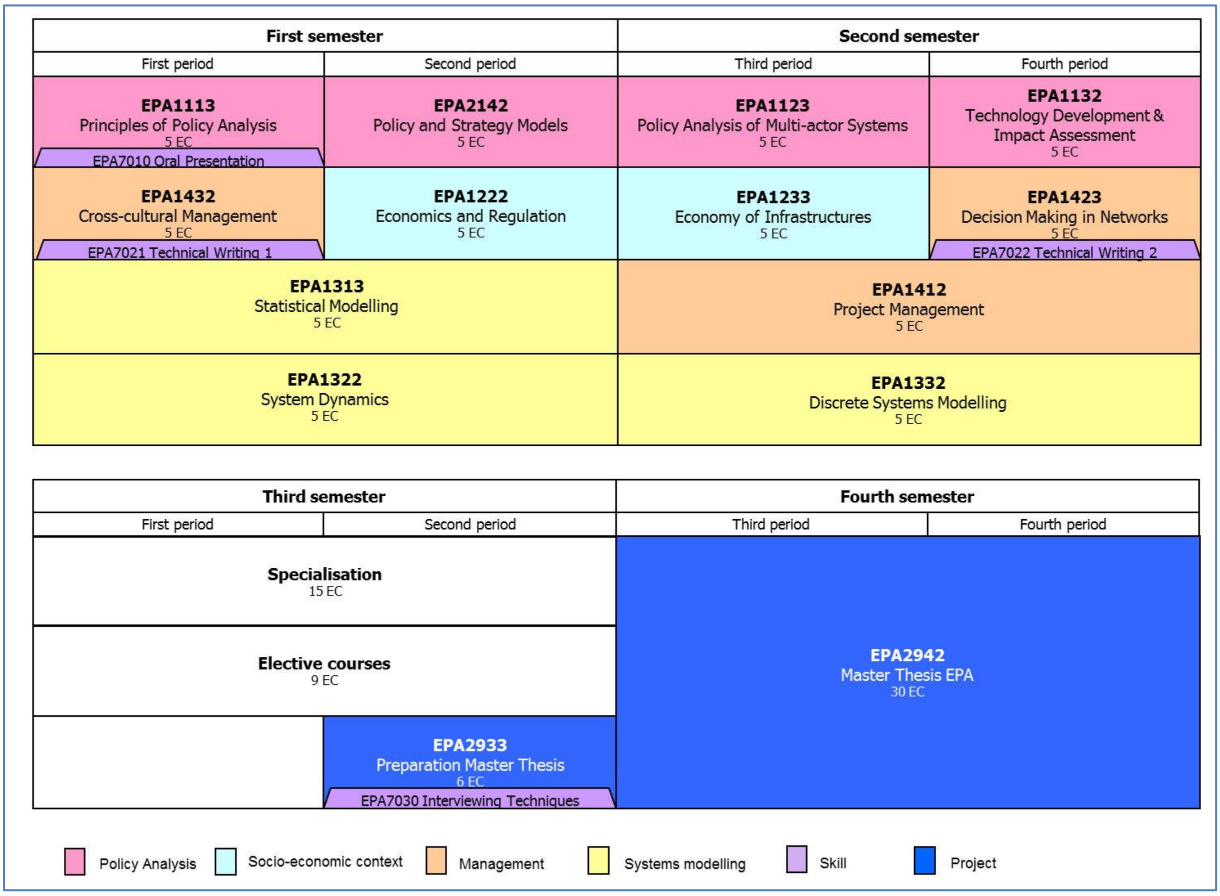

Figure 2: The current EPA MSc program

2.3 How?

The concept of active learning has had a central role in the training of TU Delft engineers (Graaff and Andernach, 2006) but recently changed to online and blended learning approaches. EPA was one of the programs participating in TUDelfts experiment with online and blended learning approaches. In the past application followed the theoretical basis in projects, games, simulations etc. Over the course of time, there was a transition from a more cognitive approach to learning towards a more constructivist approach, and from teacher centered to student centered learning (Rullmann, 2006).

Many courses in the EPA curriculum are turning into blended courses. Some of the courses recently also flipped the classroom (intense work sessions at the university instead of lectures which are largely replaced by short movies and reading at home). EPA courses also start to be available as online courses. As a result, these courses have significantly invested in e-learning, the products of which are made available to regular EPA students too.

2.4 SD in EPA 1.0

EPA students are trained in basic policy analysis up to intermediate policy analysis, including model-based policy analysis. System Dynamics modelling is one of the core modelling methods students are trained in. During the 2-year EPA master, students start with a large mandatory SD course (EPA1322), which consists of an introduction to SD modelling of 1 quarter (8-9 weeks) and a SD project of 1 quarter (5-7 weeks). This course is also available as an online course for anyone interested in learning SD (see https://online-learning.tudelft.nl/courses/systems-modelling/).

Those interested in SD can take an advanced SD course, as well as modelling masterclasses, and write a SD master thesis. Note, however, that they are trained as policy analysts, not System Dynamicists *pur sang*.

The first quarter of the 2-quarter SD course is taught following a blended case-based approach based on a free e-book (Pruyt, 2013b), with, in addition, special topics not covered in the e-book. The objective of the first quarter is to teach students the necessary technical skills to make and use SD models. During the second quarter, pairs of students do a supervised SD project on a topic of their choice. The goal of the second quarter is to learn how to build SD models from scratch and use them for policy analytical purposes. Most of the SD projects are good, that is, for a 5 week SD101 project of, in total, about 70 hours per student. In fact, many of these SD projects have been presented at the International SD Conferences. Examples include Kovari & Pruyt (2014) and Schwarz, Fakkert and Pruyt (2015).

Since many EPA students do not take the advanced SD course, there are nevertheless quite some EPA master students graduate with only basic to intermediate SD skills. The current curriculum redesign offers the opportunity to teach basic, intermediate and advanced SD (and other modelling and simulation) skills to all EPA students.

2.5 Recent Experiments and Lessons Learned

Over the past two years, several experiments regarding the SD teaching were conducted. Some succeeded, others failed but offered very valuable lessons to learn.

A first experiment that worked out well was to reduce the number of weeks for acquiring the basic modelling skills (i.e., the first part of the course based on the e-book) from (previously) 9-10 weeks down to 5 weeks.

An experiment that related to the reduction of the amount of face-to-face teaching/coaching by their professor failed to some extent: students were asked to develop their own modelling skills using the aforementioned e-book. Although their modelling skills at the exam turned out to be of the same level, about 66% of the students wanted more involvement and guidance by a professor. Without this personal guidance, 2/3 of the students found learning the System Dynamics method (too) hard, frustrating and time consuming. The remainder of the students enjoyed learning the System Dynamics method with the e-book without further teaching/coaching by a professor. But 2/3 of the students would enjoy SD much more with more personal guidance.

The inverse experiment, providing intense workshop-like teaching using the e-book was more successful: this intense teaching approach allowed to further reduce the time required to learn the basic modelling skills to three days without much practice time and 5 days with practice time included.

Other experiments related to the testing cases used at the exam. Apart from having to answer 10 multiple choice questions related to the SD method, students also need to the make a SD model following a completely new case description (like the ones in the appendices) and need to use the model for a particular policy analytical purpose. Previous experiments to use multiple choice questions to capture some of their model specification skills as in appendix A and C-E worked out well: almost all students build their models without first looking at the answers of the multiple choice questions and it tremendously speeds up the correction of these model-based exams (5 minutes instead of 30 minutes). The experiment to also capture the answers to model use questions was not successful: it did not improve student grades. To the contrary, it caused lock-in problems for students who had made severe mistakes in the specification phase. In the end, it resulted in a lot more waste of time than could possibly be gained. Using bigger testing cases and providing about 50% of the model structures and equations as in the Ebola II&III cases in appendix C was not successful either: students found the size of the overall model too hard to deal with given the limited amount of time of 3 hours in total.

Another experiment that worked out well was to reduce the number of weeks of the SD project from 7-8 weeks down to 5 weeks.

We also tested whether it was possible to facilitate large groups of students (45-200 students) in open projects (i.e., projects of their own choice) instead of pre-specified case-based SD projects. From these experiments we concluded that models of open projects may not always be as good as models of pre-specified projects, but also that students practice and develop more skills in open projects (which is what matters in our SD project setup). Interestingly, the open projects also required less instead of more hours of supervision per group than traditional pre-specified cases.

Finally we tested whether it was useful to require students to use a template with a very strict format to report their SD projects. Although students found it difficult to abide to the strict page limit, it helped students to provide exactly those pieces of information we believe modelling reports should comprise.

3. EPA 2.0

3.1 Why?

In the summer of 2014, two external triggers started off discussions about repositioning the EPA program: (i) a ruling by the Ministry of Education about termination of the so-called ‘doorstroom masters’ (the automatic continuation of a bachelor study into a specific master program) and (ii) an opportunity to relocate the program from Delft to The Hague.

Although successful in itself and one of TUDelft’s forerunners with respect to blended and online courses, changes in the ruling by the Minister now enable us to adapt our entrance requirements and to broaden our market. Where we had restricted our inflow to students with a mono-disciplinary engineering background or natural sciences background, we are now allowed to open up to those with a more multidisciplinary training, such as our own TB bachelors and bachelors from industrial design or biology and even to liberal arts students with a sufficient background in math and physics. Opening the gates to a wider variety of students also enables us to choose a more prominent modelling, simulation and gaming profile. The new EPA program will therefore be positioned as an internationally oriented master of science program in policy analysis with a focus on analytics, modelling and simulation (EPA, 2015). We will, at the same time, pay attention to the political context within which the products of the analytical work need to be used. That is, in real-world decision-making. This tension between analysis and modelling and the dynamics of the strategic decision-making context is an important intellectual challenge for the students. This challenge is reflected in the design of the program.

The second external trigger for change is the envisioned relocation of the program from Delft, the city of engineers, to The Hague, the international city of justice, seat of the Dutch national government, and city hosting many international (UN) agencies, consultants, research institutes and multi-national organizations. The presence of the latter institutions at the new location is an opportunity to make strategic alliances with these institutes and link up with policy analysts and policy makers, and structurally bring their real-world experience into our teaching and (student) research.

Content wise the program will be oriented towards dealing with grand challenges: global health, water security, environmental justice, climate change adaptation, energy security food security, water management, cyber security and the management of natural resources. Alumni from the new program will be real change agents: engaged technical policy analysts who understand the value and the limitations of analytical and modelling techniques and who want to make the world a better place for current and future generations (EPA Curriculum Committee, 2015).

3.2 What?

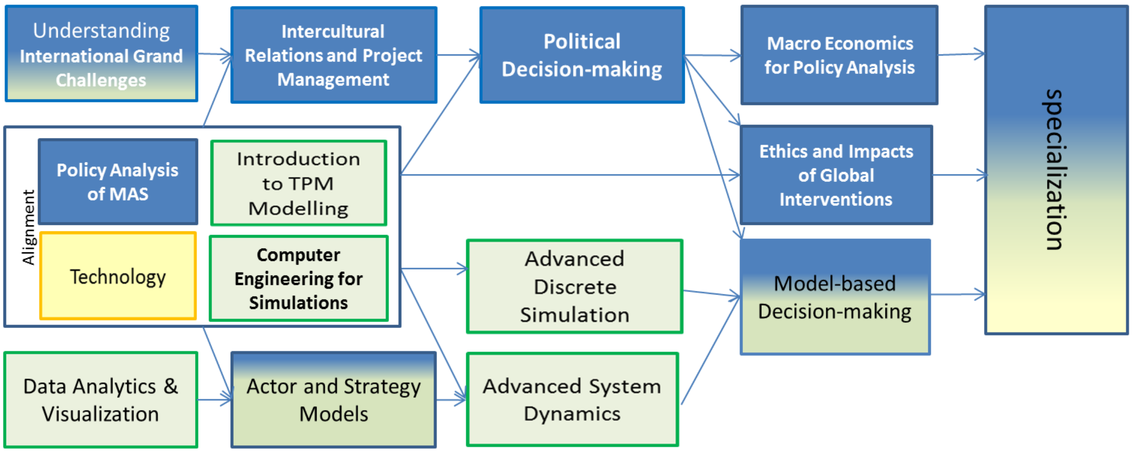

Figure 3: 2-lines philosophy of the new EPA curriculum

The new EPA program will be a blended, case based program; blended as most of the materials will be online and case based as the application and training will be done by using real cases as teaching materials in the intensive groups work and individual assignments that are part of the flipped classroom which is essential to the blended learning experience. Meanwhile there is a conscious design choice underlying the new curriculum; the story of the new EPA curriculum is about the relation between two learning lines; the modelling and simulation line and a policy and politics line (see Figure 3). These two lines are intertwined and courses are phased in such as to confront these different intellectual perspectives. To create learning windows we consciously created a number of courses that can be seen as boundary objects; modelling techniques are challenged in the policy and politics courses and stakeholder oriented courses are part of the modelling and simulation line. Moreover, concepts and models of one course are used in the next or even in parallel courses. The model-based decision-making course in the 4th quarter deliberately focusses on the limitations of modelling approaches and the preconditions for effective use of model in policy processes.

As indicated the new EPA program is positioned to attract student with a wider variety of backgrounds than the current program. Therefore in the new curriculum we have consciously chosen to integrate 10 ECTS alignment courses. In the first semester non-TB bachelors will have to follow dedicated crash courses on multi-actor systems and "TPM modelling and simulation" to allow for advanced modelling courses to be taken in later semesters (see Figure 4).

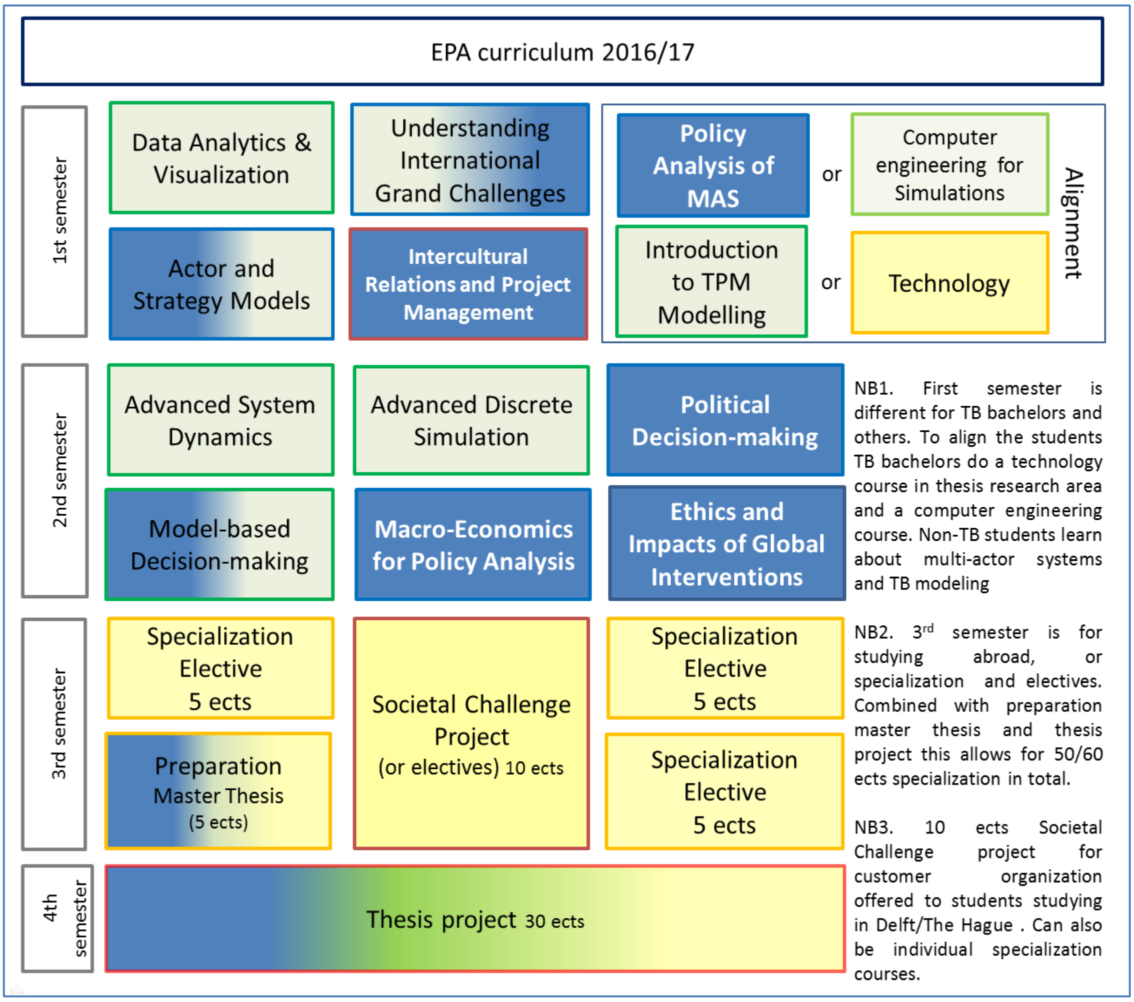

Figure 4: Design of the new EPA curriculum

3.3 How?

There are rather big challenges, apart from the challenge to move a master program to another town. First, the EPA curriculum will be pushed towards grand challenges. This means new cases need to be developed. Second, the teaching needs to be further intensified to enable students to quickly ramp up to intermediate level, no matter what their background is, from which level the core program will actually start, to reach the advanced level during the first year. Third, this redesign means that all teaching materials need to move towards advanced model-based policy analysis. This will also require furthering the methodological integration between methods and techniques. Finally, we will develop a system in which all MSc theses students are embedded in professional research teams and at relevant organizations.

3.4 SD in EPA 2.0

SD will remain a crucial method in the new curriculum, possibly more crucial than before. It will be one of the methods students will be familiarized with at the very beginning of their EPA studies. Moreover, students will already reach the advanced level during the second semester. Even more importantly, SD will be used in many other courses. Finally, many methods and techniques will be linked to SD models or applied on SD simulation results. This will require excellent SD cases, like the SD housing model in the appendix, which can be linked right away to the real-world data about the Dutch housing sector. Finally, SD is an excellent method for investigating and dealing with grand challenges. Hence, SD will most likely become even more central to the new EPA curriculum than it is in the current one. SD modeling could even become the core of an integrated model-based policy analysis cycle as visualized in Figure 5.

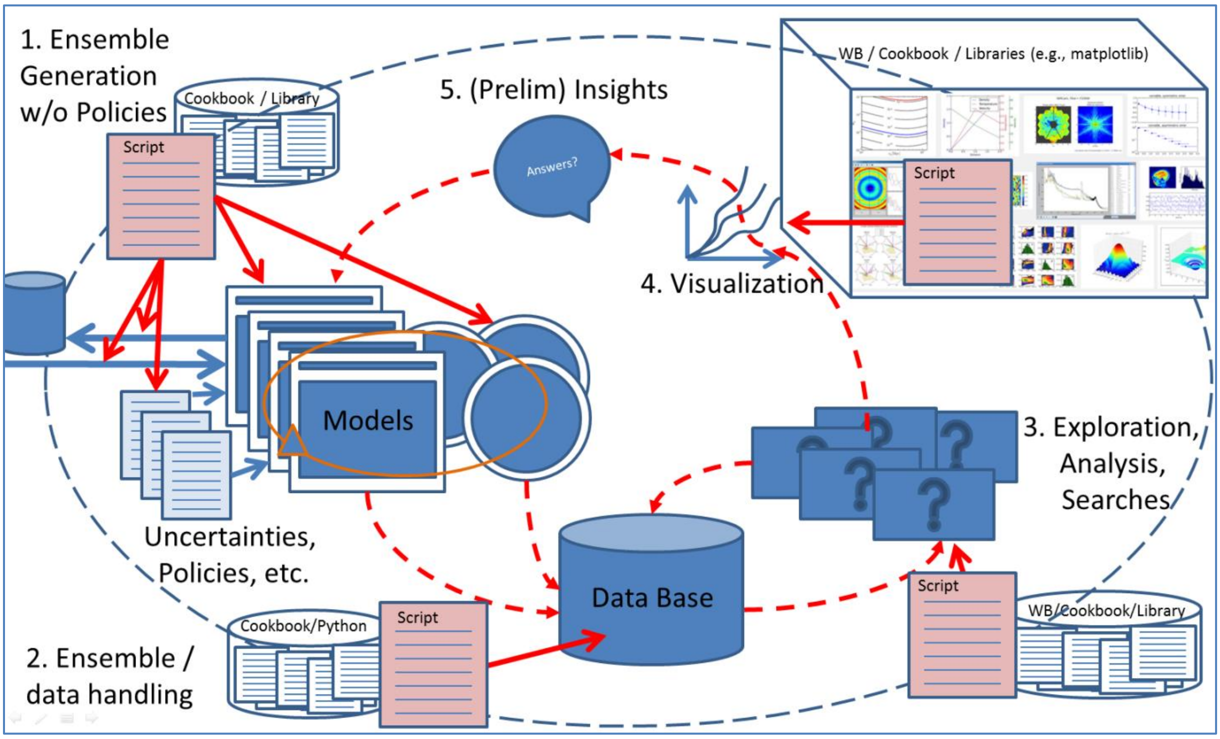

Figure 5: Integrated (exploratory) model-based policy analysis cycle

4. Concluding Remarks

The EPA curriculum is currently being restructured. System Dynamics will remain a crucial method in the curriculum. More, it may become even more important if the integration challenge with other methods and techniques is handled well. This requires furthering the field and embracing other methods and techniques.

Recent experiments have shown paths to be taken but also paths not to taken for teaching SD modelling. It seems we need more intensive approaches and that these intensive approaches could enable novices to quickly develop the necessary basic to intermediate skills required to slowly learn the advanced skills needed in an even more complex and uncertain world. A world with many grand challenges!

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