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Communication

Systems Education at Bergen

Pål I. Davidsen [1], Birgit Kopainsky [1], Erling Moxnes [1], Matteo Pedercini [2] and I. David Wheat [1,*]

[1] System Dynamics Group, Department of Geography, University of Bergen, Post Box 7800, 5020 Bergen, Norway; E-Mails: pal.davidsen@geog.uib.no (P.I.D.); birgit.kopainsky@geog.uib.no (B.K.); erling.moxnes@geog.uib.no (E.M.)

[2] Millennium Institute, 1634 Eye Street, NW Suite 300, Washington, DC 20006, USA; E-Mail: mp@millennium-institute.org

* Author to whom correspondence should be addressed; E-Mail: david.wheat@geog.uib.no; Tel.: +47-555-83-081; Fax: +47-555-83-099.

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Abstract: At the University of Bergen in Norway, educating students to use computer models and to think systemically about social and economic problems began in the 1970s. The International Masters Program in System Dynamics was established in 1995, and a Ph.D. program began a few years later. Student enrolment doubled in 2010 with the establishment of the European Master Program in System Dynamics. International diversity has been a hallmark of the Bergen program; each year, students come from about 30 different countries and more than 95% of the degrees have been awarded to students from outside of Norway. However, a Bergen systems education is not confined to a classroom in Norway. Projects in developing countries, emerging economies, and developed countries have taken the systems perspective and modeling tools on the road and, increasingly, online. Whatever the delivery mode, the goal is the same: capacity building among international students, planners and managers, and local stakeholders. This paper describes the Bergen program and its impact on systems thinking and modeling throughout the world.

Keywords: education; policy design; simulation; system dynamics; systems thinking

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1. Introduction

At the University of Bergen in Norway, graduate education in computer modeling of social and economic problems began more than forty years ago. After several years of offering various modeling courses, the university established the International Master Program in System Dynamics in 1995, and a Ph.D. program began a few years later. International diversity is a hallmark of the Bergen program, and this paper describes its approach to systems education and its impact on systems thinking and modeling throughout the world.

2. Background

The Bergen program grew out of an interdisciplinary information science program established in 1971 and chaired by Svein Nordbotten, now professor emeritus at the University of Bergen [1]. As former head of computing at the Norwegian Census Bureau, he was intrigued by the work of the American computer pioneer and MIT professor Jay W. Forrester, the founder of the modeling discipline now known as system dynamics (SD) [2]. At Bergen, Nordbotten taught a course called *Cybernetics and System Dynamics* and collaborated with other scientists at the Christian Michelsen Institute. That motivated several graduate students to write theses using the SD methodology, and software ("SIMPAS") was developed for the modeling, simulation, and visualization of complex, dynamic systems.

Years later, one former student—Bergen professor Pål Davidsen—went to MIT as a Visiting Scholar and worked with Forrester and other prominent system dynamicists on several SD projects, including *Road Maps*, an extensive set of instructional lessons aimed at developing systems thinking intuition and formal modeling skills [3]. Not long after returning to Bergen, Davidsen was asked by the university president to establish an international master's degree program in system dynamics, and the first students enrolled in the fall semester of 1995. Initially located in the Department of Information Sciences, the Bergen System Dynamics Group is now part of the Department of Geography within the Faculty of Social Sciences [4].

The number of new students each year was small during the formative period, but grew to 20 by 2009 and doubled in 2010 with the expansion of scholarships and degree options. In the fall semester of 2013, nearly 60 students took SD modeling courses in Bergen.

A constant since the beginning has been the international mix of students. In 1997, the first master's degree was awarded to a student from Ghana, and an Egyptian student earned the first Ph.D. in 2001 (Mohamed Saleh, the first Ph.D., is an associate professor at the Faculty of Computers and Information at Cairo University). In recent years, as many as 30 different countries have been represented among new enrolments, and more than 95% of the degrees since 1997 have been awarded to students from outside of Norway.

The expansion in 2010 resulted from Bergen's participation in founding the European Master Program in System Dynamics (EMSD), a joint study program with European Commission scholarship funding for both European and non-European students [5]. Bergen's founding partners include Radboud University in Nijmegen in the Netherlands, the University of Palermo in Italy, and the New University of Lisbon in Portugal. The EMSD students begin their studies in Bergen, where they take the foundation SD modeling courses during the fall semester. They move on to either Palermo or Lisbon in the spring, with the choice depending on their preference for public management [6] or sustainability issues [7]. The second fall semester reunites all EMSD students in Nijmegen, where they develop *group* model-building and organization intervention skills in issue settings that involve interaction with diverse stakeholders [8]. During the last semester of the two-year program, EMSD students write their theses at one of the four universities and receive degrees from the specific universities they attend.

The original vision, including the international perspective, still guides the Bergen program. The goal is to educate future planners and managers so they will be able to: (1) use computer-based modeling, simulation and visualization in the identification and analysis of complex, dynamic problems that span social sectors and scientific disciplines; (2) identify solutions to such problems in the form of strategy development, policy design, and decision making; and (3) help stakeholders understand relationships between the structure and dynamics of social systems. This computer-based modeling approach utilizes a systems thinking perspective and, in turn, enhances that perspective. The synergistic value emerges from the iterative process of thinking systemically about the world around us, formulating equations to specify our thoughts, observing simulation results, analyzing a model's structure in light of its behavior, and then refining that computer model *and our mental model* to reflect new insights and their policy implications.

Opportunities to learn about SD are available worldwide, and the International System Dynamics Society maintains a list of universities offering courses on every continent ([9]). However, as noted by other authors in this issue, the "programs that offer substantial coursework in system dynamics and a degree titled 'System Dynamics' can be counted on one hand" [10]. The University of Bergen is on that short list.

3. Curriculum

The masters curriculum in Bergen consists of six SD modeling courses during the first year and a thesis during the second year. In addition, special topics courses are offered each semester. Each course consists of 36 lecture hours and 18 computer lab hours, and most projects require an independent student modeling project.

During the fall semester, first-year students take three foundation courses sequentially. The first, *Principles of Dynamic Social Systems* [11] is taught by Erling Moxnes and gives an introduction to the SD method. Students learn to recognize typical problematic behaviors of dynamic systems, exemplified by global warming, overgrazing, unemployment, epidemics, and price fluctuations. They learn how to represent hypotheses for social problems, and how to use simulation to understand ways that systemic structures produce problematic behavior. Students experience how easily dynamic systems can be misperceived, and they witness examples of well-intended but malfunctioning policies [12]. The course also gives students training in applying the scientific method to socioeconomic problems, and it provides a common language for interdisciplinary research.

Davidsen, the founder, teaches the second course, *Model-based Analysis and Policy Design* [13]. Students gain extended knowledge about the SD method, with particular emphasis on model-based problem identification and analysis as well as hypothesis formulation and analysis for policy design. They gain knowledge about the intimate relationship that exists between structure and behavior (dynamics) and the shifts in causal loop governance that may take place in non-linear systems. They learn to recognize the significance of a robust strategy development and the associated policy design and decision-making. Students apply their knowledge in a series of comprehensive case studies. The compact learning content of these case studies allows the students to recognize and investigate the dynamic properties of generic system structures, as they appear in a variety of domains. The case studies are presented in class and the students are challenged to address each of them using modeling and simulation, addressing problem identification and validation on the one hand and policy design and impact assessment on the other. Each exercise is followed by an extensive de-briefing session. Particular emphasis is placed on student recognition of dynamic patterns of problematic behavior and the corresponding underlying structures, as well as student ability to formulate and assess the impact of policies designed to address such problems. Students are trained to distil the essence of their insights and present it in the form of compact causal loop diagrams to facilitate effective communication with potential stakeholders.

The third course, *System Dynamics Modeling Process* [14] is taught by David Wheat. This project-based course is devoted to developing skills needed to build *explanatory* models of dynamic problems that emerge from real-world complex social and economic systems. Each student has an intense six-week assignment to build an SD simulation model that represents a plausible, operational, and systemic explanation of a specific dynamic problem. With as many as 50 students in the course, the supervisory work is also intense, and three teaching assistants are employed to help the instructor provide timely guidance to each student modeler.

In 2010, Wheat developed a new course—*Policy Design and Implementation* [15]—which is now fourth in the curriculum sequence. Student learn to build feasible (instead of wishful-thinking) policy models and communicate effectively with policy makers and staff about policy options, drawing on both the SD and public policy and management literature. The individual policy modeling project requires each student to (1) restructure a pre-existing explanatory model of a dynamic problem with a feasible policy for alleviating problematic behavior cost-effectively, (2) develop an interactive simulator to help policy makers and staff improve their mental models of the issue and their assessment of the cost-effectiveness and feasibility of particular policy options, and (3) write a short report that identifies policy implementation obstacles and suggests strategies for dealing with those challenges. The course utilizes a framework to help SD modelers envision operational requirements of their simulation-based policies and build more useful models [16–18].

Experimental Methods in Social Systems [19] is the fifth course, and it provides theory and methods for the design, programming, and analysis of laboratory experiments. Building on previous instruction in simulator development, this course includes optimization to establish performance benchmarks and statistics for hypothesis testing. Students design and carry out their own pilot laboratory experiments with a focus on purpose, hypotheses, design, and analysis. For their individual projects, students can design experiments to address behavioral theories or learning interventions [20]. The experimental methods course complements the modeling courses by strengthening the link with more traditional scientific methods.

Model-based Socioeconomic Planning [21] is the final required course in the first-year curriculum. Conceived by Davidsen and adjunct lecturer Matteo Pedercini (a Bergen Ph.D.), the course is currently organized and taught by Pedercini with assistance from senior research fellow Birgit Kopainsky. It is unique because of its origin as a course designed for planners and managers in developing countries, in conjunction with national planning assistance provided to those countries by Millennium Institute consultants such as Pedercini [22,23]. Now, in addition to the sponsored participants from developing countries, all Bergen degree students take the course and experience immersion in a realistic and problematic development setting.

Students take on roles as strategic planning consultants to “Zambaqui”, a hypothetical country facing common developmental issues such as poverty, high mortality, land degradation, and water scarcity. The multiple and diverse issues make the exercise especially challenging and engaging. Early on, the need to adopt an integrated approach becomes evident: changes taking place in one sector cause changes in all other sectors. Using group model building methods [24], instructors lead students through the development of a small, basic integrated SD planning model for Zambaqui’s government. The background analysis of the key issues is based on joint exploration of relevant data and multimedia from actual countries, a search of relevant literature, and interactive discussion, all with the aim of developing a shared understanding of the nature of such issues and their importance for development. Students then work in teams that address different issues facing the country and develop issue-specific models to be merged with the integrated model. Students must provide practical answers and policy recommendations to Zambaqui’s government, as well as deal with misunderstandings and delays in communication that are introduced with the specific intent of recreating a realistic modeler-client exchange. Such training enables graduate students as well as professionals and researchers in the field of sustainable development planning to use quantitative methods to strengthen their analytical capacities. Post-training surveys indicate a high degree of satisfaction with the course and after several years former students from around the world still recall their trip to Zambaqui as a fundamental step in their SD education journey through Bergen.

4. Beyond the Traditional Classroom

A Bergen systems education is not confined to a Bergen classroom. The authors—three professors and two lecturers—manage active travel schedules and work with students, stakeholders, clients, and colleagues facing pressing issues around the world. Pedercini’s work for the Millennium Institute and Kopainsky’s research projects funded largely by the Norwegian Research Council build systems thinking and modeling capacity with a wide range of stakeholders in developing countries. Currently, these activities support integrated planning for facilitating transitions towards a green economy, adaptation to climate change, and food security at different institutional levels.

A senior research fellow at Bergen, Kopainsky focuses her efforts on the multitude of ecological, economic and social processes that affect food production and distribution. Specifically, she uses a food systems approach to address policy issues surrounding environmental change and food security in sub-Saharan Africa. She uses SD to foster understanding of leverage points and preconditions for a transition to sustainable, equitable and resilient agri-food systems [25] and diffusion of desired policies among smallholder farmers and other concerned stakeholders [26]. Her current work builds on parallel food systems research in Switzerland, where she and her colleagues built an SD model to prioritize policy options aimed at closing an ever widening gap between food demand and domestic food supply in the context of rising pressure on the natural resources used for food provision [27]. Her systems education challenge involves food producers, processors, distributors, retailers, and consumers [28].

Using SD-based experiments to evaluate alternative instructional strategies for transferring knowledge, she concludes that performance and understanding can be improved when stakeholders interact with a simulation in an exploratory but stringently guided way [29,30].

Davidsen, Moxnes, and Wheat have exported SD to the Baltic region. In Latvia, they worked with colleagues at Riga Technical University to develop systems thinking and modeling skills among graduate students and faculty, and then assisted on a major energy conservation project [31]. In Lithuania, Wheat's initial guest lectures at ISM University of Management and Economics evolved into three SD-based courses in applied microeconomics, in monetary policy, and in public finance. With funding from the Department of Geography at Bergen, his research on the systemic interaction of economics and demographics was extended to the problems associated with a declining and aging population in the small Baltic state. The methodological approach is relatively unknown there and has caught the attention of demographers, economists, and policy analysts [32–35].

Wheat's use of SD to teach economics [36–39] was instrumental in gaining support from the Norwegian Centre for International Cooperation in Education so he could work with Ukrainian colleagues to develop SD modelling capacity within the finance department at the National University at Kiev-Mohyla Academy [40,41]. The three-year project funded four workshops in Kiev and enabled twelve graduate students and two assistant professors to spend a semester in Bergen. In addition to taking three basic modeling courses, they participated in Wheat's macroeconomics seminar to develop an SD model of the still-struggling economy in Ukraine. To sustain the collaboration beyond the three-year funding period, he is developing an online curriculum that builds on a dozen years' of experience teaching online SD-based economics courses to students in the United States [42]. The reaction from students has been encouraging; for example:

> Female Ph.D. student: *System dynamics was a completely new tool for me. I had never heard about it before. The same with Norway—I didn't know anything about the country. Both were the best experiences ever—system dynamics as a useful and interactive modeling tool and Norway as an extremely beautiful country with tolerant and welcoming people*.
>
> Male Ph.D. student: *System dynamics serves as a bridge between modeler and client, which increases the usefulness of mathematical modeling. The structural approach—the core feature of system dynamics—develops operational thinking and increases understanding of socio-economic problems in the real world.*

Moxnes also uses technology to teach across the globe. He has developed an interactive online distance-learning course in *Natural Resources Management* [43] that convenes a worldwide virtual classroom. The course aims to build intuitive understanding of the theories and principles underlying the utilization and management of natural resources, which are often mismanaged with dramatic consequences for stakeholders. A second objective is to help course participants develop skills and competencies needed for proper management of resources such as water reservoirs, fisheries, forests, animal herds, non-renewable resources, and climate. The course makes use of online animations and simulators to give students practice in decision-making and develop their intuition about the dynamics of natural resource management. Students are challenged by increasingly complex tasks to construct knowledge themselves. Online suggested solutions and videos give immediate feedback and encourage generalization of insights.

5. Going Forward

The systemic nature of social and economic problems is increasingly evident to observant citizens around the world. Developing international capacity to address such problems has been the hallmark of a systems education at Bergen. Yet, designing and delivering a systems education is a dynamic problem in itself. We know that, as educators, we must adapt our methods to meet the dynamic and increasingly complex educational challenges ahead. Our confidence going forward is rooted in the ideals, enthusiasm, and encouragement of our students, whether they are in a classroom in Norway, on a computer screen in Kiev, or on the road to Zambaqui.

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Author Contributions

All authors contributed equally to this work.

Conflicts of Interest

The authors declare no conflict of interest.

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