Localizing Socio-Environmental Problem Solving

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Abstract: In this paper, we describe *iPlan*, a web-based software platform for constructing localized, reduced-form models of land-use impacts, enabling students, civic representatives, and others without specialized knowledge of land-use planning practices to explore and evaluate possible solutions to complex, multi-objective land-use problems in their own local contexts.

Introduction

Many of the world's most pressing challenges consist of *socio-environmental systems*: complex interactions among human (social, political, economic) and natural (biophysical, ecological, environmental) processes (Elsawah et al., 2020). Although it is critical to understand socio-environmental systems in order to address challenges such as global climate change, it is difficult for educators to make them accessible to learners. The scale of such systems makes individual actions seem meaningless, while the slow rate of change can lead learners to underestimate their own vulnerability. In other words, it is challenging to help students *understand* socio-environmental systems without *disempowering* them to take action on socio-environmental problems.

However, socio-environmental problems can also invoke the "disorienting dilemmas" that Mezirow (1997) suggests can lead to transformative learning. These dilemmas can provoke reflection and stimulate action, helping learners (re)examine their own and others' assumptions and view problems and proposed solutions from different perspectives. But transformative learning can only take place if learners are able to see socio-environmental problems as personally relevant to themselves (Monroe et al., 2019).

To make complex, often global problems personally relevant to learners, one effective approach is to *localize* them (Siebert-Evenstone & Shaffer, 2019). This situates authentic, real-world problems in a real place with which learners are familiar. But it is not sufficient for learning simply to transplant complex processes into some specific context, even one familiar to learners. To cultivate both understanding of socio-environmental systems *and* the belief that something can be done about socio-environmental problems, learners need to be able to take consequential actions and see the results in order believe that those actions are meaningful (Barab et al., 2009). This can be achieved through *reduced-form models*, simplified models that make complex systems more accessible to learners, stakeholders, and other non-experts without compromising the general accuracy of the underlying relationships and outputs.

In this paper, we describe *iPlan* (Ruis et al., 2020), a web-based software platform for constructing localized, reduced-form models of land-use impacts. These localized land-use models enable users to (a) construct *land-use scenarios* (Xiang & Clarke, 2003) that relate specific zoning policies to projected effects on socio-economic and environmental indicators and (b) explore how simulated stakeholders with various priorities react to proposed scenarios. *iPlan* thus enables students, civic representatives, and others without specialized knowledge of land-use planning practices to explore and evaluate possible solutions to complex, multi-objective land-use problems in their own local contexts.

iPlan: A Platform for Constructing Localized Land-Use Models

iPlan enables users to select any location in the contiguous United States using Google Maps and choose up to five ecological and socio-economic indicators to include in the model. The indicators in *iPlan* reflect issues that are frequently invoked in land-use planning contexts, including measures of air and water pollution, greenhouse gas emissions, wildlife population levels, agricultural production, commercial activity, and housing.

Based on the location and indicators selected, *iPlan* generates (a) a land-use map of the selected region with at most 200 parcels, based on land-cover raster data and U.S. Census data, and (b) nine virtual stakeholders—business owners, activists, and concerned citizens—who advocate for different issues that the indicators reflect. *iPlan* uses a set of optimization routines to divide the selected region into parcels, assign an appropriate land-use class to each parcel, and set stakeholder thresholds—minimum or maximum satisfactory values—for the selected indicators. The effect of each land-use class on each indicator is modeled either at the national level (for socio-economic indicators) or at the biome level (for environmental indicators). All models were derived using spatial data, ecological simulations, or published findings. Collectively, this process results in localized, reduced-form models that are realistic and appropriately complex for non-specialists, who can use *iPlan* to explore the scientific and social challenges involved in land-use planning and management.

In *iPlan*, the goal is to produce a new land-use plan for the modeled region that satisfies as many stakeholders as possible. To do this, learners (a) consult resources on the land-use classes, indicators, and simulated stakeholders; (b) use a map interface to model the effects of specific land-use changes on the selected indicators; (c) create land-use scenarios and submit them to the virtual stakeholders for feedback; and (d) utilize a graphing tool to estimate stakeholders' preferences. Learners have a limited number of feedback requests, so they are challenged to conduct experiments, or *stated preference surveys* (Tagliafierro et al., 2016), that help them determine with more precision the amount of change each stakeholder finds acceptable.

Because the simulated stakeholders have different and often conflicting demands, learners must identify and negotiate trade-offs. For example, one stakeholder may advocate for an increase in jobs, which is easiest to accomplish by rezoning parcels for commercial or industrial use, but another stakeholder may want a decrease in greenhouse gas emissions, which will increase with commercial or industrial expansion. Thus, *iPlan* models not only the *effects* of land-use change on socio-economic and environmental indicators but also the *acceptability* of land-use change to various civic interest groups. That is, *iPlan* constructs models that help people learn about the scientific and civic practices through which land-use planning is managed and contested, helping them understand land-use management as a socio-environmental system.

To enable *iPlan* to construct realistic, accessible land-use models of any location in the contiguous United States, we developed and validated three primary functions: (1) a *parcelization optimization routine* that divides each user-defined region into approximately 200 contiguous parcels and assigns a land-use class to each parcel based on geospatial land-cover data and U.S. Census data; (2) a set of *land-use impact models* that quantify the effect of each land-use class on each indicator; and (3) a *stakeholder threshold optimization routine* that selects the minimum or maximum acceptable level that a stakeholder has for a given indicator. In what follows, we explain in brief how the system achieves each of these objectives. More thorough explanations and evidence of validity will be presented in a future publication.

Land-Use Data and Parcelization of User-Defined Regions

We derived the baseline geospatial data for *iPlan* from the NWALT (U.S. Conterminous Wall-to-Wall Anthropogenic Land Use Trends) dataset developed by the U.S. Geological Survey (Falcone, 2015). We reduced the original 20 land-use classes to 11 by removing unneeded classes and consolidating similar ones, which decreases the cognitive complexity of the land-use models and ensures that the resulting classes can function as zoning codes for the purposes of constructing land-use scenarios. After consolidating the NWALT land-use classes, we constructed four co-registered map layers at increasingly coarse scales using 2010 U.S. Census data. Each layer contains contiguous polygons—census blocks, census block groups, census tracts, or counties—and each polygon in a layer is assigned a single land-use class. Land-use classes were assigned by selecting the class associated with the largest proportion of area in each polygon based on the underlying (reduced-class) gridded raster land-use data. This geospatial aggregation can produce much simpler representations that retain a high degree of accuracy (Lark et al., 2021). To generate a land-use map of a user-defined region that has broadly accurate land-use classes but a small enough number of distinct parcels to be accessible to non-specialists, we developed a parcelization optimization routine that operates on the constructed map layers. The goal of the optimization is to produce a land-use map of the user-defined region that has no more than 200 parcels, which prior work suggested would provide an appropriate level of complexity for high school and adult learners (Bagley & Shaffer, 2009). This is accomplished by selecting the nearest map layer with >200 parcels and aggregating them into 200 parcels by implementing a heuristic based on minimum spanning trees and local search, which produces near-optimal solutions in very little time (typically less than 10 seconds).

Modeling the Impacts of Land Use on Indicators

The *iPlan* system models the impacts of 11 land-use classes on 18 indicators. The relationship between each land-use class j and each indicator i for any map in a given biome is computed using a linear equation, $I_{ij} = m_{ij}a_j$, where I_{ij} is the value of indicator i contributed by land-use class j, m_{ij} is a multiplier that characterizes the impact of each hectare of land-use class j on indicator i, and a_j is the total area in hectares of land-use class j in the map. The value of each indicator i for the whole map, then, is given by the sum of the values of I_{ij} : $I_i = \sum_{j=1}^{11} m_{ij}a_j$. Thus, the key challenge is to derive the values of the multipliers m_{ij} such that the relationship between a given land-use class and a given indicator in each biome is as accurate as possible given the geographic scale and the availability of existing data and models. For indicators for which spatial data were available, such as Jobs and Housing Units, we co-registered the indicator data with the census block map layer, then computed the mean contribution of each land-use class to the indicator at a national scale to estimate the value of the indicator per hectare of each land use class. For indicators for which spatial data could be imputed, such as Added Heat Advisory Days, we used PEGASUS (Deryng et al., 2011), a reduced-form model that estimates ecosystem photosynthesis and net production using a light-use efficiency approach combined with surface energy and soil water budgets, to generate spatial data. For indicators for which spatial data were neither available nor were able to be modeled at this scale, such as Birds and Butterflies (for which we used American robins [*Turdus migratorius*] and monarch butterflies [*Danaus plexippus*] as index species), we derived multipliers based on published findings that report relationships between indicator levels and land-uses by area.

While this approach enables learners to explore the impacts of land use on indicators, a key feature of *iPlan* is the ability to submit land-use scenarios to simulated stakeholders. Thus, the system needs to assign stakeholder preference thresholds that are realistic and appropriately challenging relative to the initial map.

Automated Assignment of Stakeholder Preferences

Because each land-use model created by the *iPlan* system a unique result of user selection and non-deterministic optimization, the preferences of the virtual stakeholders need to be set automatically such that the resulting land-use problem space is neither too simple nor too complex. To do this, we constructed 57 virtual stakeholders, each of whom has a name, image, job, brief biography, stakeholder group, and indicator. We developed 57 so that each of the 18 indicators is associated with one member from each of the three stakeholder groups. For each stakeholder, we also determined whether they prefer their assigned indicator to be above or below some threshold.

The system selects nine stakeholders for each land-use model based on the indicators chosen and a prioritization algorithm, then runs an optimization routine to set the indicator threshold for each stakeholder. The objective of the optimization is to set the thresholds such that the distribution of land-use scenarios that satisfy some number of stakeholders matches a target distribution. The target distribution we use is based on prior work, but a key advantage of this approach is that the difficulty of *iPlan* simulations can be adjusted simply by adjusting the target distribution. Because there are 11^{200} possible land-use scenarios that can be constructed for a given land-use model, we use a sampling process to generate a set of reasonable land-use scenarios for that model, which in turn generates distributions of indicator values from which to select and optimize threshold levels.

iPlan Usage

Preliminary research indicates that learners are able to use iPlan to develop land-use scenarios that increase the overall approval rate of the virtual stakeholders. Of the 132 learners who submitted at least two land-use scenarios for a given iPlan model since version 1.0 was released in 2021, 116 (88%) were able to generate a land-use scenario that increased the number of stakeholders satisfied. That is, most learners were able to propose a new plan that successfully addressed at least some of the stakeholders' concerns. Both educators and learners themselves have successfully constructed and used *iPlan* models in a variety of subject areas and learning contexts, including in units on sustainable cities, ecological restoration, human geography, and general biology. The following examples illustrate three ways educators have integrated *iPlan* into their curricula.

Introduction to STEM Disciplines and Careers. At an urban high school with a predominantly Black and Latine student population in Rhode Island, *iPlan* is part of a climate science and land-use unit designed to help students understand how land-use planning can address environmental challenges like the greenhouse effect but that there are trade-offs in doing so. The teacher also felt it was important to link professional activities to social impacts, and to motivate students to take civic action. "I wanted students to . . . see that *they* could be stakeholders." During one semester, the unit took place during a heat wave, prompting a conversation about the relationship between land-use and extreme heat in the context of climate justice. Although the students often express a kind of hopelessness at the beginning of the unit—"Can we ever get to net zero?"—after using *iPlan*, "students felt more confident that there are things that can be done."

Life on Earth, Localized. At a high school in rural Massachusetts, *iPlan* is used in a unit on land-use planning in a "Life on Earth" course. The school's town is currently considering proposals for redevelopment of a large site near the school. After using *iPlan* to learn about land-use planning practices, explore multi-objective problems with no perfect solution, experience the challenge of representing diverse perspectives, and understand quality indicators, the students produce a plan for the site and an accompanying vision statement to help them understand one way young people can engage in civic decision-making; willing students then submit their plans to the local planning board, whose members, according to the teacher, "were absolutely floored [that students] were actively engaged in the planning process." *iPlan* provided "a direct link between . . . school learning and this very important project that has the potential to influence . . . [their town] for decades to come."

Field Biology. At a large high school in rural New Hampshire, *iPlan* is used as part of a "Field Biology" elective. In the "Freshwater" unit, students learn about runoff and pollution, conduct water quality tests of a nearby lake, and then use *iPlan* in the same location as their testing site. They use *iPlan* to try to improve the health of the lake while also accommodating a growing population. "They know the health of the lake is not great," the teacher said, "so they don't want to do anything [in *iPlan*] to make it worse." *iPlan* helps interest the students in the way land-use planning can be used to address the effects of climate change, such as warming temperatures leading to declining water quality in the lake, which is an important part of the local ecology and economy. The teacher reported that "every student was engaged, even my students who always put their heads down," because they could take meaningful action on issues that otherwise felt remote and unchangeable.

Discussion

iPlan was designed so that any user could easily and quickly create a reduced-form land-use model for any location in the contiguous United States, and both educators and students (aged 14 and older) have been able to use the system in this way. While *iPlan* has mostly been used in remote learning conditions due to the COVID-19 pandemic, interviews with educators indicate that (a) the system creates realistic representations of local conditions, (b) educators can construct simulations that meet their curricular and pedagogical needs, and (c) *iPlan* is an effective educational technology, especially for learners less motivated by more traditional curricula. In addition, *iPlan* provides a model for enabling non-specialists to construct and use reduced-form models to investigate and solve complex, multi-objective problems. In future papers, we will describe in more detail the design and technical features of the *iPlan* system; provide evidence that the geospatial consolidation, land-use impact models, and stakeholder preference optimization routine produce accurate land-use models; and model the effects of *iPlan* on learning processes and outcomes.

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