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Co-creating Visualizations: A First Evaluation with Social Science Researchers

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Abstract

Co-creation is a design method where designers and domain experts work together to develop a product. In this paper, we present and evaluate the use of co-creation to design a visual information system with social science researchers in order to explore and analyze their data. Co-creation proposes involving the future users in the design process to ensure that they play a critical role in the design, and to increase the chances of long-term adoption. We evaluated the co-creation process through surveys, interviews and a user study. According to the participants' feedback, they felt listened to through co-creation, and considered the methodology helpful to develop visualizations that support their research in the near future. However, participation was far from perfect, particularly early career researchers showed limited interest in participating because they did not see the process as beneficial for their research publication goals. We summarize benefits and limitations of co-creation, together with our recommendations, as lessons learned.

CCS Concepts

• ***Human-centered computing*** → ***Visualization design and evaluation methods;*** *Collaborative and social computing;*

1. Introduction

Visualization designers have multiple approaches on how to organize the design process of custom visualizations. In recent years, there has been a rise in human-centered design approaches under the umbrella of user-centered design [LD11, MSM15] to elicit user requirements, accompannied by an increasing interest in creative methods to discover visualization design opportunities [GDJ*13, KGD*19]. Participatory methodologies have been mentioned [HF06, LHS*14, KAKC18] but are still rare, and therefore, understudied in visualization design research. *Co-creation* is a design methodology that proposes to design not only *for* the future users, but also *with* them [San08]. It is based on the principles of mutual learning, empowerment, openness and diversity, involvement and ownership, transparency, and effectiveness [BDI16, JKG*19]. The future users are valued as co-creators by the design experts, and the aim is to increase satisfaction and long-term adoption by including the validation of the people affected early on.

We present a visualization case study of using co-creation as a design methodology to create an information system *with* and *for* social science researchers. Nowadays, there is an increasing availability of large datasets for social science research, thanks to the open government initiative and the rise of social media. Therefore, social scientists are integrating programming into their workflow to analyze their data. However, the technical skills of the community are not growing as fast as the amount of data available. Consequently, they are increasingly collaborating with computer scientists to develop tools that support their data exploration and analysis. In our case, we collaborated with a group of social science researchers to design a visual information system that supports them in their research on social policy data. We are all part of an interdisciplinary project, in which political scientists, sociologists, geographers, economists, and computer scientists collaborate to describe and explain social policy phenomena.

We considered co-creation a suitable approach for this scenario because experts of diverse disciplines needed to develop a shared understanding of their goals across domains, and co-creation aims to support mutual learning towards developing a product that fulfills the tasks. We hypothesized that the co-creation principles (mutual learning, empowerment, openness and diversity, involvement and ownership, transparency, and effectiveness) would be achieved by applying the co-creation methodology to the design of the system. Achieving the principles meant that the co-creators would learn from each other, feel empowered, consider the process open and diverse, feel involved and in ownership of the designed system, feel that the process was transparent and that it led to an effective design. Although participatory approaches have an inbuilt evaluation embedded [BDI16], we used specific methods such as surveys

and interviews to assess how the co-creators perceived the process according to the principles.

Regarding the domain goals of the experts, our aim was to analyze their research tasks to identify visualization opportunities. Through the co-creation process, it became clear that the social scientists want to explore the data to discover temporal and geographical patterns which, in combination with their domain expertise, lead them to generate research hypotheses that can be later tested with the data. We elicited the requirements to design such visualizations, and developed multiple prototypes of the visual system in an iterative process. The resulting system includes more than 400 indicators about social policies (e.g. "Government expenditure on health") applied worldwide over the last 140 years. It allows the social science researchers to explore their data through topic pages (e.g. "Health and long-term care") and country profiles, as well as by combining and comparing multiple indicators. We released a first version of the system within our project and continue working on new features based on the researchers' feedback. They share their data across the project through the system and plan to cite it in their publications.

In this paper, we focus on describing the co-creation process we have conducted, and a first evaluation of the design methodology. We conducted three co-creation workshops, two surveys, a round of interviews, and a user study with 14 social science researchers. An overview of the process is shown in Figure 1. After the second workshop, we conducted a formative evaluation of the process with an evaluation survey, interviews, a group discussion, and the documented reflections of the facilitators. After the last workshop, we conducted a summative evaluation by means of a user study, in which the researchers interacted with the system and were interviewed to learn more about their experience, not only with the visualizations, but also with the whole co-creation process. Through co-creation, participants felt listened to, and felt empowered by learning about data visualization. However, in the formative evaluation, they were not confident about the effectiveness of the methodology to develop visualizations that support their research. They preferred to receive a finished product within a shorter time frame, instead of committing to a long-term research process they may not benefit from right away. After testing the first prototype of the system in the user study, researchers were more positive about the usefulness of the visualizations for their research. Overall, they most valued working together with their peers in the workshops, as well as creating a system tailored to their research collaboratively. To our knowledge, this is the first evaluation of co-creation as a visualization design methodology. We share our insights to guide visualization researchers and practitioners who are considering using co-creation as a methodology for visualization design.

2. Related Work

The origin of co-creation goes back to the participatory design (PD) movement that emerged in Scandinavia in the 1970s. This movement started with a political agenda that claimed that everyone affected by a decision should have the opportunity to influence it [LJS*18, SN93]. In the case of information technology design, the motivation was the transformation of the workplace due to the introduction of computers, and the aim was to ensure that people who use this technology play a critical role in the design [SR12]. We apply this participatory mindset to our scenario to design data visualizations that facilitate the work of social science researchers.

According to Sanders and Stappers, co-creation is any act of collective creativity, and co-design is collective creativity applied throughout a design process. However, these terms are often used interchangeably [SS08]. Sanders [San08] argues that design researchers with a 'participatory mindset' design *with* the people because they value the future users of the tool as *co-creators*. The opposing 'expert mindset' refers to designing only *for* the people. In the private sector, research has shown that co-creation has a positive effect on the customer's satisfaction and loyalty [GSS12]. In the public sector, co-creation is considered a cornerstone for social innovation and one of its main goals is citizen involvement [JKG*19, VBT15]. Dörk and Monteyne [DM11] define the involvement of citizens in urban planning and design as urban co-creation. Furthermore, co-creation has been used to work with specific audiences, such as blind people [UF15] and elderly individuals [BSK*17]. In the field of learning analytics, Dollinger and Lodge [DL18] claim that co-creation has the potential to increase flexibility as well as the chances of long-term adoption. Drawing on these insights, we chose to co-create with our domain experts to increase the chances of success and adoption of the system, given that we work in an academic context and have the possibility to work closely with them.

In the field of visualization research, Landstorfer et al. [LHS*14] co-created a visualization with network security engineers to support the inspection of large log files. Based on their experience with those domain experts, they proposed several principles for co-creation such as defining and refining requirements with the stakeholders face-to-face, using real data from the stakeholders as early as possible, brainstorming and sketching with the users, and rapid prototyping. In a geo-visualization case study, Lloyd and Dykes [LD11] concluded that using real data is key to understanding the needs and design possibilities, and that paper and virtual prototyping enable successful communication. Paper prototyping is particularly good at eliciting suggestions for novel visualizations. We followed these principles and insights in our design study. Furthermore, Kerzner et al. [KGD*19] recently proposed a framework for creative visualization-opportunities workshops with multiple guidelines and methods. We used and adapted their methods of Creativity Guidelines, Wishful Thinking, Visualization Analogies, and Reflective Discussion in our co-creation workshops.

Regarding the effects of co-creation and similar participatory methods, Frishberg [Fri11] and Kahng et al. [KAKC18] reported that facilitating participatory design sessions helped them identify important needs in their case studies. According to Steen et al. [SMDK11], further research is necessary to evaluate the co-design method according to its intended benefits and to assess its costs and risks, for instance, comparing the organization costs with the outcome of the project. Mitchell et al. [MRM*16] investigated the impact of co-design when generating sustainable travel solutions and found that co-design promotes idea generation and a holistic view of the problem. In contrast, we investigate the co-creation with social science researchers, to report its benefits and limitations for visualization case studies.

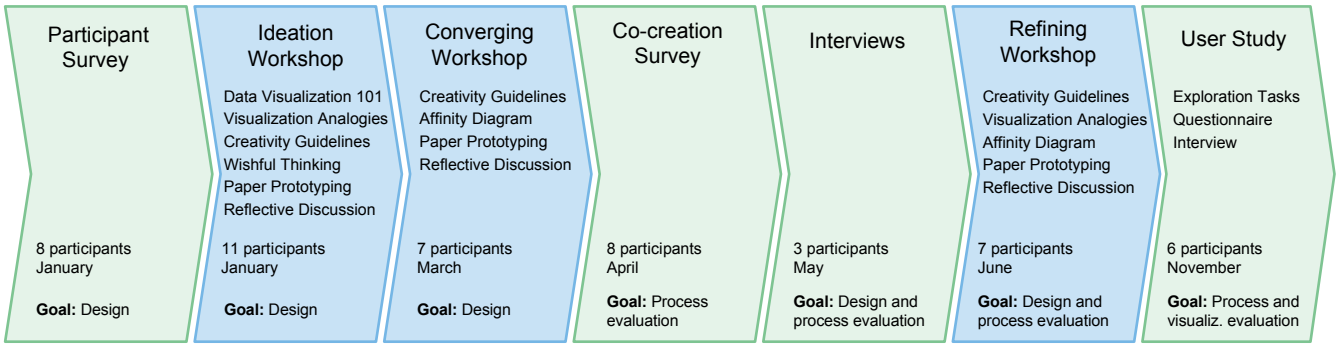


Figure 1: *Overview of the co-creation process. The workshops are in blue and include the methods used. Although each step has specific goals, the evaluation of the design is also inbuilt throughout the whole process [BDI16]. In total, 14 social science researchers participated.*

3. Methodology

This work presents a qualitative case study based on a year-long collaboration of the authors with four research groups of social science researchers working together in a collaborative research center. Fourteen researchers decided to take part in the co-creation process to design a visual information system led by the authors. As co-creation focuses on the use of workshops for collaborative design, we conducted three co-creation workshops combined with surveys, interviews and a user study. Collaborative design means that the domain experts would take part not only to help elicit the requirements but also to propose their design ideas. Based on sucessful examples of related literature [GDJ*13,KGD*19], we applied multiple workshop methods, such as Wishful Thinking and Paper Prototyping, described in Section 4. Furthermore, we observed the participants and documented each activity. Before and after each workshop, the facilitators filled out a reflection form to document their plans, impressions and experience. They wrote down the planned activities for each workshop, then what happened during the workshop, and afterward, what they learned from it. In particular, the form served to compare the workshop goals with the outcome and to reflect on the events to plan the next steps.

With the co-creation principles in mind, we wanted to assess whether applying co-creation as a design method would lead participants to feel empowered, involved, and to learn from each other, among others. To evaluate the use of co-creation, we conducted a formative and a summative evaluation. The formative evaluation included a survey after the second workshop, a round of interviews, and a reflective group discussion in the third workshop. Although our sample was small, the survey results gave us an overview of the participants' experience through the co-creation process. Then we conducted semi-structured interviews to better understand the workflow of our co-creation partners and their experience through the process. With the written consent of the participants, we recorded and transcribed the interviews. We used the co-creation principles to develop a coding scheme for analyzing the interviews, that we later adjusted during the analysis. The analysis helped us to assess whether the principles were being achieved and to plan the next workshop accordingly. In the last workshop, we organized a reflective discussion that we also transcribed and analyzed.

Once the prototype of the visual information system was ready, we conducted a summative evaluation through a user study. The study consisted of a series of tasks, a second survey and a final interview. Interviews were both about the designed system and about the co-creation process. We recorded, transcribed and qualitatively analyzed them, producing a coding scheme that led us to identify the core topics. Based on the documentation of the workshops, the observations, and the other methods just mentioned, we then proceeded to critically reflect on what we learned from this case study. In Section 4, we present each step of the process together with the evaluation results, and the critical reflections on our experience. In Section 5, we present the lessons learned.

4. Our Co-creation Process

In the context of a large interdisciplinary project, we worked together with 14 social scientists to analyze how technology can support their work, and to design a visual information system accordingly. These researchers are investigating the global evolution of social policies over the last century, and work in different research groups according to the topics they specialize in: social security, labor, economic relations, health care, education, and family policy. During the preliminary meetings with each group, visualization came up as one of the main topics they were interested in. They want to visualize their time series and network data in order to explore it with the goal of finding patterns that lead them to formulate their research hypotheses, or help them to work on these hypotheses. We started by studying the data portals of international organizations the researchers were familiar with, such as the World Bank [The] and the Organisation for Economic Co-operation and Development (OECD) [Org]. However, we also had to consider that the main goal of the social scientists was to focus their research on new data that they planned to collect, and our collaboration was going to happen parallel to the data collection process.

Based on this information, we planned a co-creation process to explore the possibilities and opportunities for data visualization to support their work. Throughout the process, we iteratively co-designed and developed visualization prototypes, following the double diamond design process model [Des15]. This model first encourages divergent thinking to define the problem,

and then convergent thinking to find the best solution. We organized a series of workshops that combined creativity techniques from related literature [GDJ*13, KGD*19] with a focus on paper prototyping and rapid software prototyping, to elicit novel ideas and easily adjust the design, as suggested by previous case studies [LD11, SMM12]. Designing collaboratively in the workshops aimed to ensure the deep involvement of the co-creation partners, mutual understanding, and a continuous 'built-in' validation of the visualizations [LHS*14]. In each iteration, we started designing together on paper – either proposing new ideas or annotating printed prototypes – and then produced or refined corresponding software prototypes. The core design sessions took place in the workshops, while the software implementation was done by the visualization researchers after each workshop. Our method choices were based on design processes for creative visualizations [KGD*19], and previous co-creation projects [JKG*19, LJS*18]. In each workshop, there was a main facilitator leading the methods, a second facilitator taking care of the organizational aspects, and a documenter. Each workshop took half a day and was documented with a co-creation reflection form [JKG*19]. In the form, we first wrote down our intended goals and planned activities for the workshop, then what actually happened in the workshop, and afterward, we reflected on whether we reached our goals and what we learned.

To help participants learn from each other and to counter the influence of power hierarchies, we asked participants to work with people from different research groups whenever possible. Besides the workshops, we conducted surveys and interviews to get input not only from the group activities, but also at the individual level. Overall, we conducted two surveys, three workshops, a round of interviews, and a user study, complemented by the preliminary meetings and informal discussions. The process is shown in Figure 1. Each step is explained in the following sub-sections. The whole process took over a year and had 14 participants: two full professors, five postdocs, six doctoral students, and one master's student.

We evaluated the co-creation process through the co-creation survey, the interviews, and the discussion in the refining workshop, as well as with our continuous reflection through the co-creation reflection form. Since we asked participants to write down their answers in color-coded cards in the different workshop activities, we were able to then read and analyze them, to reflect on what happened. Based on related literature on the evaluation of participatory design and co-creation [BDI16, JKG*19], we evaluate the co-creation process according to the following criteria: (1) mutual learning, (2) empowerment, (3) openness and diversity, (4) involvement and ownership, (5) transparency, and (6) effectiveness. We apply these principles to our case, not only based on related literature, but also because a successful interdisciplinary collaboration includes developing a shared understanding. Effectiveness is evaluated through the qualitative feedback of the participants. We present our evaluation findings in more details in Sections 4.4, 4.6.1 and 4.7.

4.1. Participant Survey

First, we conducted a survey to learn more about the stakeholders and their previous experience with data visualization. We sent it to the researchers who expressed interest in participating in the workshops, and used the results to prepare the content of the workshop. We asked nine questions about the researchers' background, the data they work with, their use of visualizations at work (if any), and the reasons for using them. The survey is included in the supplementary material of this paper.

Eight researchers took part in the survey: four political scientists, two geographers, one sociologist and one economist. All of them work with tabular data — six of them specifically with time series. Four work additionally with networks. When asked about how often they use visualizations at work, four of them replied 'usually', and one 'always'. Regarding their motivation, six have used visualizations for presentations with their colleagues, while five have used them for data exploration. Based on these results, we planned the first workshop focusing on the use of networks and tabular data for the tasks of presentation and data exploration.

4.2. Ideation workshop

Keeping in mind the goal of developing a collective shared understanding across disciplines, we started the first workshop with an introduction called Data Visualization 101. We presented Munzner's analysis framework [Mun14] to explain how we can systematically explore the visualization design space, specifically the data, the tasks, and the visualization and interaction techniques. We then showed diverse examples related to their data and their tasks in Visualization Analogies, to inspire and to give an overview of the possibilities. After the visualization-focused content, we used Wishful Thinking [GDJ*13] to learn about the social science perspective. The participants expressed their research aspirations by answering three questions: (1) "What would you like to *know*?", (2) "What would you like to *be able to do*?", and (3) "What would you like to *see*?". Answering these questions individually and discussing the answers with the group helped participants to make their goals and expectations more concrete. In previous meetings, we had already received initial visualization suggestions from the researchers. However, as Sedlmair et al. [SMM12] suggest, a common pitfall in design studies is that domain experts think about the solution before thinking about the problem. This is why we asked our co-creation partners to first focus on their wishes.

Furthermore, we did early paper prototyping following the recommendation of Koh et al. [KSDK11], allowing the experts to sketch their design ideas early on. The goal was to start collecting visualization ideas that would correspond to their wishes. The main workshop facilitator took the position of an active collaborator, as described in the co-creation framework of Lee et al. [LJS*18]. This means that the facilitator actively participated in the idea generation and decision making. Each participant drew at least one prototype. A selection of the prototypes is shown in Figure 2(a). The most common visualization techniques used were maps and networks, and five participants drew and described multiple coordinated views. Each participant explained orally what they would expect to happen if interaction was included, and the most common interaction technique was the selection of a particular indicator or time frame. Two participants wished to save their queries. After the workshop, we applied *parallel prototyping* [DGK*11] to design multiple low-fi prototypes covering the design space as broadly as possible. We analyzed and clustered the paper prototypes accord-

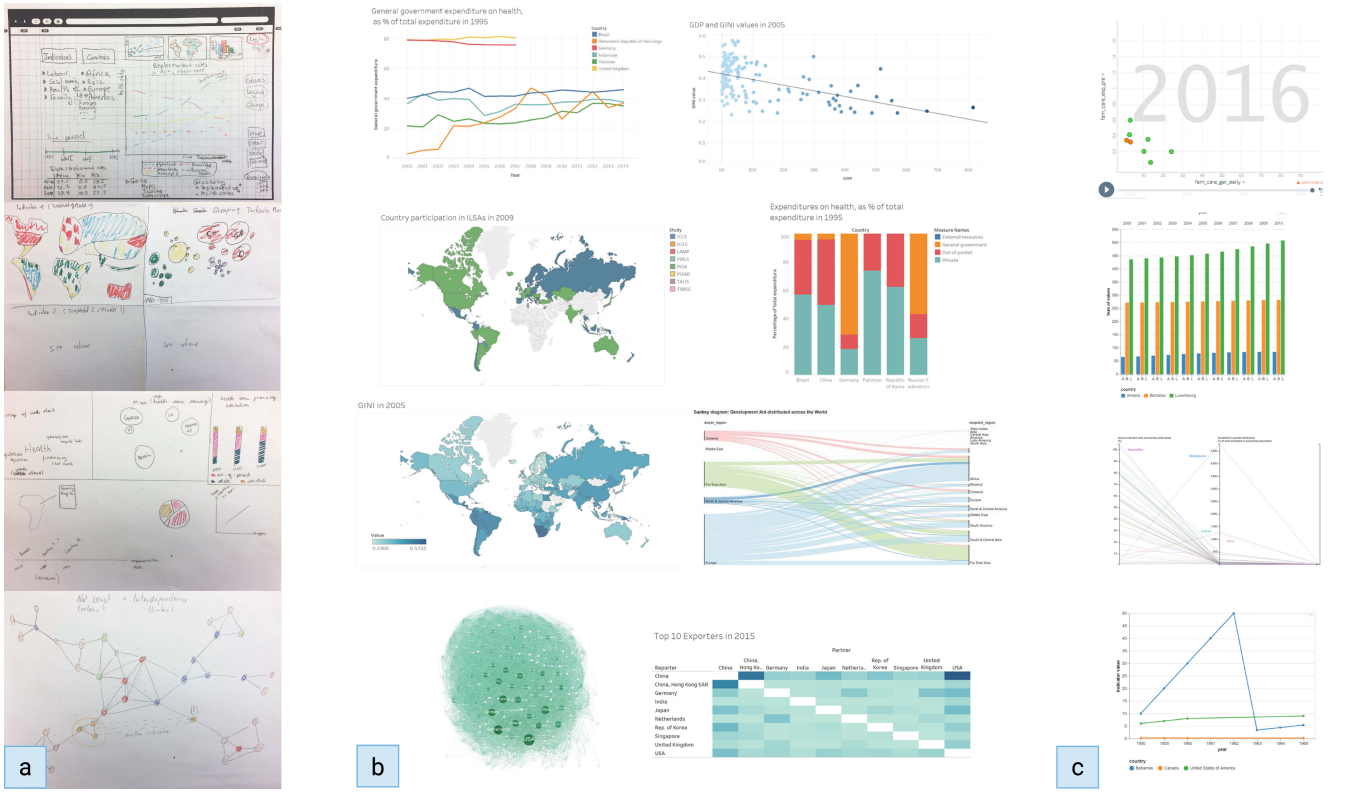


Figure 2: *(a) A selection of the paper prototypes from the ideation workshop. (b) Software prototypes from first iteration. (c) Second iteration. We used Tableau, Vega-lite, D3.js, and other tools to translate the core ideas of the paper prototypes into interactive visualizations, complemented with other relevant techniques. For example, we translated the drawn line charts and scatterplots first into interactive equivalents (on the top), and then created an animation of the scatterplot according to the participants' feedback.*

ing to the common topics and ideas. For each one, we documented the type of data, the tasks, and the techniques considered. Then we used this information to create software prototypes to present in the next workshop (see Section 4.3). In the reflective discussion, participants expressed that the most valuable activity was Data Visualization 101.

4.2.1. Reflections

Starting with Data Visualization 101 encouraged some participants to focus on visualization solutions too soon. We chose to give the introduction first to provide an overview of the topic before brainstorming, and to lead by example on exchanging domain expertise. Although participants were very positive about learning the basics of visualization, Wishful Thinking answers were focused on designing visualizations. Doing Wishful Thinking before would have allowed the participants to first focus on the task. Participants seemed to have a hard time developing their own ideas from scratch. They felt more comfortable discussing existing examples, and their ideas were often a reflection of the visualizations they have interacted with on the websites of the World Bank [The] and other international organizations. Furthermore, they focused on describing scenarios to explore their data. This indicated that their main interest was data exploration.

4.3. Converging workshop

In our co-creation process, we aimed at following the double diamond design process model [Des15]. In this model, co-creation starts with divergent thinking, i.e. imagining possibilities, and then proceeds to convergent thinking, i.e. agreeing on alternatives. Since the ideation workshop focused on divergent thinking by enabling participants to discuss initial ideas and to explore visualization possibilities, the converging workshop aimed to define the problem more specifically by reaching agreement. Accordingly, we had a group discussion to agree on the tasks that everyone needed to tackle, and this led to creating an Affinity Diagram about the researchers' workflow. This activity resulted in agreeing on four steps that describe the researchers' workflow: (1) discover time and geographical patterns in the indicators, (2) generate hypotheses, (3) test the hypotheses through statistical data analyses, and (4) explain the patterns. Discussing the workflow with the whole group led to developing a shared understanding of the common problems.

When we invited the participants to this workshop, we asked them to send us examples of their data. In the workshop, we presented 10 visualization prototypes that used their data, based on the ideas we had discussed in the ideation workshop. Some of them are presented in Figure 2(b). We converted the paper-based ideas into software prototypes and complemented them with more vi-

sualization techniques according to their data and tasks, following Munzner's framework [Mun14]. For instance, we translated the paper-based node-link diagrams of country relationships into a network prototype and then included a Sankey diagram because the researchers sent us data about development aid and were interested in the distribution of aid across world regions. The prototypes included standard interaction techniques such as selection and showing tooltips on hover to help users explore the data. We asked the researchers to analyze the prototypes in small groups, and then to share their thoughts for the next iteration. Our goal with rapid prototyping was to quickly get feedback from our co-creators, understand them better, and refine the prototypes, as well as the requirements accordingly [FMC*12]. Participants were finally able to see how their ideas can be combined in a concrete product. In the reflective discussion, one participant was positively surprised that the researchers had more in common than expected, and two mentioned that they appreciate that co-creation is a continuous process where they get a chance to provide feedback quickly.

4.3.1. Reflections

The steps of the research workflow that we agreed on almost perfectly match the description of the *discover* task by Munzner [Mun14]. Experts want to use visualizations to discover data patterns that help them to generate hypotheses and later test them. Therefore, the definition of the workflow led us to successfully abstract their main goal. Preliminary requirements originated from the workflow, such as comparing indicators, combining time and space attributes of related indicators, and identifying similarities and differences across them. Showing initial visualizations with data provided by the researchers made a big difference for the participants. This made the progress of our collaboration concrete and visible.

4.4. Co-creation survey

To perform a formative evaluation of the co-creation process, we conducted a survey with the social scientists after the converging workshop. The questionnaire had 16 questions: eight questions with statements to rate from 1 (strongly disagree) to 5 (strongly agree), two open questions about the workshop content, two open questions about their personal involvement, two questions about participation and two about demographics. The questions were meant to assess whether the co-creation principles had been followed. For instance, we asked what did they learn from participating in the process to find out if mutual learning took place. The complete questionnaire is included as supplementary material of this paper.

Eight participants took part in the survey. An overview of the answers concerning participant agreement with the eight statements is shown in Figure 3. Although the sample is small, the results yield some meaningful insights. The three researchers who participated in both workshops had a higher level of agreement with every statement than the other participants. All participants agreed with the statement "I feel listened to". On the other hand, participants were least convinced about having an equal chance to be part of the decision making, and about the co-creation leading to visualizations that assist their research. Three participants answered that creating the affinity diagram about their workflow was the most

Figure 3: *Survey answers for the eight statements about the co-creation process up until the converging workshop.*

useful activity, while paper prototyping was most useful for two. The preferred workshop activities were paper prototyping and the group discussion that led to create an affinity diagram of the researchers' workflow. Others pointed out that the co-creation process has helped them to better understand what their colleagues are doing. When asked how to improve the workshops, there was no consensus but multiple suggestions were given, such as teaching how to create visualizations with the tools they are most familiar with, and spending more time on discussing existing tools and how to improve them.

4.5. Interviews

We conducted and recorded semi-structured interviews to better understand the researchers' workflow and their thoughts on co-creation. To this end, we organized a series of open questions in two parts. The first one concerned the researchers' role in the project, the research tasks, and the artifacts used by the researcher within those tasks. It also included discussing the workflow from the converging workshop. The second part was about the motivation to participate in the process, as well as the expectations about the co-creation process and about the visualizations, at the beginning of our collaboration.

We conducted a pilot interview, followed by three interviews with researchers from different research groups: one doctoral student, one postdoc, and one professor. Later we transcribed and analyzed the interviews. The first part of the interview reflected that the current task of the researchers is data collection. They pointed out that the research workflow of the converging workshop had not fully started yet, because the data collection takes most of their time. The artifacts they presented were data sources and programming scripts to collect data. Two researchers pointed out that they will never collect all the data they wish to have, due to a lack of data from specific world regions and time frames.

The second part of the interview was about evaluating the pro-

cess so far. We asked participants a series of open questions about their motivation to participate, their expectations of co-creation and of the visualizations before the process started, as well as their opinion about the results so far. Their main motivation to participate and initial wish for the co-creation process was to learn how to create visualizations on their own. They were satisfied with the introduction in the first workshop, but they would like to know more about tools they can use to create visualizations with. According to two participants, data visualization is a major opportunity for better communicating social science research, especially to the general public:

"*If we could get better visualizations, our work would become more useful. That I'm sure of*" — P3

"*Visualization is the stepchild of social sciences... there's a lot to be done. Therefore, this project is a great opportunity to make steps further*" — P10

However, P3 pointed out that social science researchers may be interested in complex visualizations, while the general public may be not. On the one hand, P3 and P10 often reflected on what would be best to show to the general public, although the system is meant to be used by social scientists. On the other hand, P7 defined the usefulness of the visualizations according to whether they are ready in time for the next publication. It was not clear when the visualizations will be delivered to them.

Regarding the start of the design process, P10 would have preferred starting with existing visualizations from the domain instead of brainstorming from scratch. He found it hard to develop new ideas without having any visualization expertise. Regarding the progress on designing the information system, the participants had the impression that no decisions were made yet because the visualization prototypes shown individually in the second workshop were not yet embedded in the system.

4.6. Refining workshop

The main goal was to refine the user requirements based on the researchers' workflow, as well as to analyze the prototypes according to the requirements. We went through the four steps of the research workflow, and discussed the most important features that the system should have to support their workflow. First, participants split into small groups to discuss, starting with the preliminary requirements based on previous workshops and interviews. We then refined the requirements with the whole group, and prioritized the most important ones. The following requirements were raised, in order of relevance:

1. Enable to interactively change the threshold values of analysis variables and visualize the change.
2. Show an overview of the missing data.
3. Provide tools to divide continuous variables into categories.
4. Select and compare indicators over time.
5. Combine and order time events from different indicators.

Afterwards, we presented the software prototypes of the second development iteration. They combined improved versions of the prototypes of the converging workshop with new ideas and previous prototypes that participants were satisfied with. Some of them

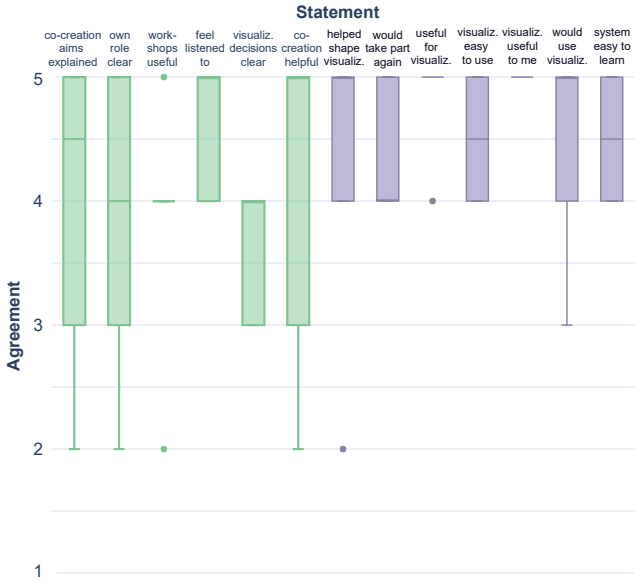


Figure 4: *Survey answers for statements about the visualizations presented in the user study and about the co-creation process. The color green represents questions that were also asked in the previous survey (see Figure 3) and purple represents new questions.*

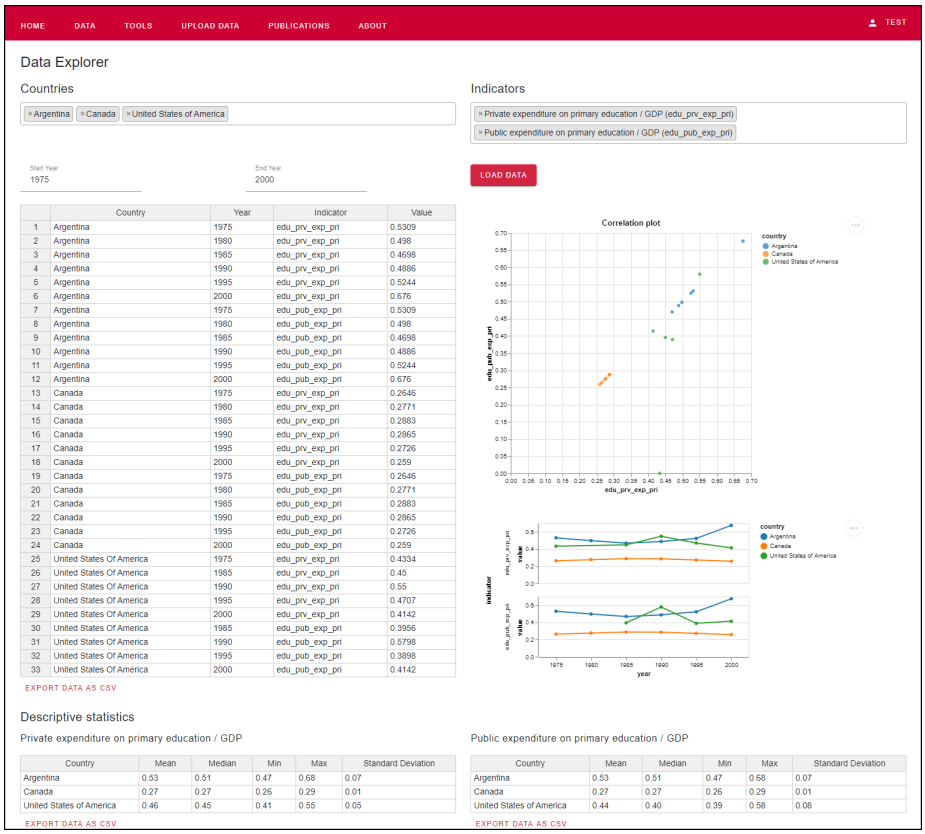
are presented in Figure 2(c). We handed out printed versions and asked researchers to analyze them according to the requirements. This activity resulted in a selection and combination of five prototypes that researchers considered as having the most potential to fulfill the requirements.

4.6.1. Reflective Discussion

We concluded the workshop with a reflective group discussion where we presented the most relevant results of the co-creation survey, to collectively assess the process according to the co-creation principles. We asked participants to reflect on the reasons behind the survey results. Here we describe the discussion based on our posterior analysis of the transcription. The effectiveness for each individual and the commitment to the process were the main topics of discussion. Effectiveness was divided into two categories: the effectiveness of the final visualizations, and the effectiveness of the process for the everyday tasks of each researcher. While the final visualizations may be useful in the future, participating in the process requires a high level of commitment and the short-term impact is unclear, especially for doctoral students eager to advance quickly in their research. Therefore, the ability to create visualizations on their own is more valuable than relying on the success of a long-term process. One participant even suggested that this mindset may be a problem among researchers.

"*...our projects are so specific that we will each probably have some visualization that we actually do that we don't expect [the system] to provide for us because no one else will need it, so it's not a public good*" — P3

"*Most researchers I know don't like to rely on others' decisions...*



	Country	Year	Indicator	Value
1	Argentina	1975	edu_prv_exp_pri	0.5309
2	Argentina	1980	edu_prv_exp_pri	0.498
3	Argentina	1985	edu_prv_exp_pri	0.4698
4	Argentina	1990	edu_prv_exp_pri	0.4886
5	Argentina	1995	edu_prv_exp_pri	0.5244
6	Argentina	2000	edu_prv_exp_pri	0.676
7	Argentina	1975	edu_pub_exp_pri	0.5309
8	Argentina	1980	edu_pub_exp_pri	0.498
9	Argentina	1985	edu_pub_exp_pri	0.4698
10	Argentina	1990	edu_pub_exp_pri	0.4886
11	Argentina	1995	edu_pub_exp_pri	0.5244
12	Argentina	2000	edu_pub_exp_pri	0.676
13	Canada	1975	edu_prv_exp_pri	0.2646
14	Canada	1980	edu_prv_exp_pri	0.2771
15	Canada	1985	edu_prv_exp_pri	0.2883
16	Canada	1990	edu_prv_exp_pri	0.2865
17	Canada	1995	edu_prv_exp_pri	0.2726
18	Canada	2000	edu_prv_exp_pri	0.259
19	Canada	1975	edu_pub_exp_pri	0.2646
20	Canada	1980	edu_pub_exp_pri	0.2771
21	Canada	1985	edu_pub_exp_pri	0.2883
22	Canada	1990	edu_pub_exp_pri	0.2865
23	Canada	1995	edu_pub_exp_pri	0.2726
24	Canada	2000	edu_pub_exp_pri	0.259
25	United States Of America	1975	edu_prv_exp_pri	0.4334
26	United States Of America	1985	edu_prv_exp_pri	0.45
27	United States Of America	1990	edu_prv_exp_pri	0.55
28	United States Of America	1995	edu_prv_exp_pri	0.4707
29	United States Of America	2000	edu_prv_exp_pri	0.4142
30	United States Of America	1985	edu_pub_exp_pri	0.3956
31	United States Of America	1990	edu_pub_exp_pri	0.5798
32	United States Of America	1995	edu_pub_exp_pri	0.3898
33	United States Of America	2000	edu_pub_exp_pri	0.4142

Country	Mean	Median	Min	Max	Standard Deviation
Argentina	0.53	0.51	0.47	0.68	0.07
Canada	0.27	0.27	0.26	0.29	0.01
United States of America	0.46	0.45	0.41	0.55	0.05

Country	Mean	Median	Min	Max	Standard Deviation
Argentina	0.53	0.51	0.47	0.68	0.07
Canada	0.27	0.27	0.26	0.29	0.01
United States of America	0.44	0.40	0.39	0.58	0.08

Figure 5: *This is a screenshot of the Data Explorer, one of the system features evaluated in the user study. We co-designed this page where users can combine data of multiple countries and indicators, including descriptive statistics, to compare different indicators over time.*

it's always hard to commit to such a broad process... it's not a criticism [of the process], it's more of a self-criticism" — P14

Understanding the computer scientists better and learning about the needs of other social scientists were the main advantages of the process that participants agreed on. Mutual learning helped to better understand how the system could be useful for the researchers. Overall, the participants who had participated in every workshop were much more positive than those who did not. This may indicate a relationship between the degree of participation and their satisfaction with the process.

4.6.2. Reflections

The refined requirements we agreed on reflect not only data exploration, but also analysis. This may be a result of the researchers feeling that exploration has been already tackled, and then moving on to the next steps in their research workflow. Three of the six workshop participants had not participated in the previous workshop. For them, the goal of our process seemed the least clear because they had not experienced the evolution of the ideas. They led the group discussion that focused rather on the overall commitment to the process and its connection to their everyday research tasks.

4.7. User study

After working on the next iteration of visualization prototypes and integrating them in the system, we invited the researchers to try them out individually. The resulting web system allowed users to upload social policy indicators and to explore them. It included a descriptive page for each indicator with visualizations such as stacked bar charts and choropleth maps dynamically generated according to the data type. Furthermore, it had a world overview page with an interactive map, country profiles with a summary of the main indicators, and a Data Explorer page that allowed to combine multiple indicators to look for correlations and other patterns. A screenshot of the Data Explorer is presented in Figure 5. In the study, the researchers performed three tasks, filled out a questionnaire and were interviewed. This was the first time they saw the visualizations integrated into the information system. This seemed to make a big difference for them, in comparison to seeing them separately before. The questionnaire aimed to learn more about their views on the co-creation process after seeing a further advancement and having the opportunity to interact with the system. In the semi-structured interview, we looked back at the whole process and reflected on how it led to the current result. The details of the user study are included in the supplementary material.

Six participants took part in the user study. Three of them (P1,

P2, P3) had attended each of the three workshops, while two participants went once and another one twice. First, we asked participants to perform four exploratory tasks that led them to navigate the main features of the system: (1) Missing data overview, (2) Browsing by topic, (3) Browsing by country, and (4) Data Explorer. In each task, the participants had to reply questions such as "How did the enrollment rate in primary education of the United States change over time since 1880?". The questions were meant to guide them through the system and to interact with the visualizations. We observed them, asked them to think aloud and allowed them to ask for help if necessary. All participants responded the task questions correctly. They were happily surprised because the visualizations were automatically generated based on the indicators, the countries and the time frame they chose. Although a data table was always shown next to the visualizations (see Figure 5), they often looked only at the visualization and used the tooltip to check the data values. They particularly liked the possibility of combining any group of indicators — which is not possible on most websites they work with, and the corresponding scatterplots generated. While participants considered the time-based line charts useful to describe the data, they saw the scatterplot as an analysis tool because of regression analyses they often use looking for correlations.

After completing the exploratory tasks, we gathered feedback from the researchers with a questionnaire and an interview. The questionnaire was about the visualizations and the co-creation process (see supplementary material). An overview of the answers is shown in Figure 4. According to the results, everyone found the visualizations useful and easy to use. Participants appreciated having the option to download the visualizations, but would have liked to be able to change the labels and colors. In certain features such as the country profiles, participants wished to personalize the content. In contrast to the previous survey (see Figure 3), participants considered the workshops more useful to them after interacting with the prototype, and they agreed more on the co-creation of visualizations being helpful for their research. They found the workshops useful to design the visualizations, and they would be open to participating in another co-creation project.

The final interview focused on qualitative feedback about the co-creation process. We discussed the co-creation principles of involvement and ownership, mutual learning, effectiveness, and openness and diversity. Three participants mentioned that co-creation is a new experience for them. Over time, they realized that their role was not just being a consumer asking for a product, but rather being a participant in the process of building the product. P1 noted that this experience contrasted with everyday shopping, where he is used to rather checking the existing options and just choosing one of them. When asked about their influence in the outcome of the project, only P5 could see her personal influence in a particular feature of the system. Most participants had a hard time seeing their personal influence. They rather saw the influence of the group and the result of their collective effort. The system actually represented the requirements and features they agreed on.

What participants liked most of the co-creation process was the interaction with the other researchers. Learning about their data, as well as recognizing the similarities and the differences across their tasks. The workshops were the events in which they most learned

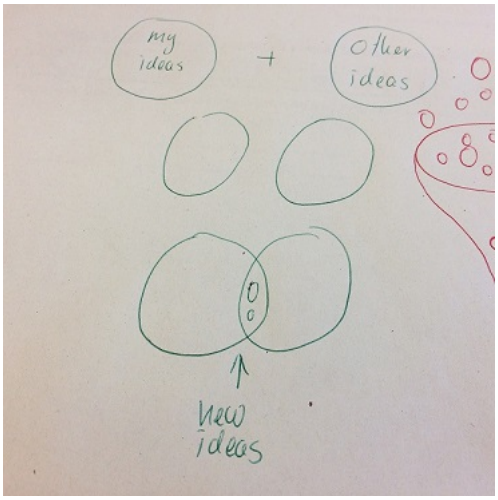


Figure 6: *Drawing of P2 used to explain how the group work led to new ideas, better than the sum of everyone's ideas.*

about their colleagues' work. The second most positive aspect was to create a tool tailored to their research. According to P2, working in groups made their ideas better than the sum of all individual ideas. He explained this with the drawing shown in Figure 6. When asked about what they liked least, P2 and P3 found it problematic that many participants were not present in every workshop. This led to repetition, and they had the impression that those participants could not really follow the progress. P1 also pointed out that it would have been better to have more principal investigators participating. These three participants attended every workshop. In contrast, P5 and P6 mentioned that doctoral students need to focus on publishing papers and participating in the workshops felt like a task that may not necessarily help them with their publications.

Overall, participants found it challenging to start designing the system from scratch. The reasons were two-fold: their feeling of lacking enough technical expertise, and the large size of the design space. Four participants expressed that they were impressed after seeing the prototype. Everyone pointed out that having options such as combining multiple indicators, the descriptive statistics, and the multiple visualizations made this system a better choice than the websites of international organizations they are used to work with.

5. Lessons Learned

Here we present our lessons learned for researchers and practitioners alike, who consider using co-creation as a visualization design methodology, based on our co-creation experience. These lessons are the result of our analyses and reflections on co-creating with social science researchers as domain experts. In particular, the lessons L1, L2, and L4 are mainly based on our observations in the workshops and the reflection form. L3, L5, and L6 became clear through the interviews and the user study, and L7 was mostly discussed in the last reflective discussion and the interviews.

L1: Incorporate an introduction to visualization after defining the problem. In the first workshop, the introduction called Data

Visualization 101 was especially welcomed by the domain experts, who expressed their interest in learning more to further develop their skills. However, this happened too soon in our case, and we had to push the discussion back to the problem space.

L2: Help participants to feel comfortable as co-creators. Participants often pointed out that they did not feel confident enough to design visualizations because they were not experts on the topic of data visualization. It is important to emphasize that their domain expertise is valuable and necessary for a successful design process. To help developing creative solutions, previous research on promoting creativity in visualization design offers multiple successful methods [GDJ*13, KGD*19].

L3: Balance openness and commitment. One of the main challenges of the process was working continuously with a large and diverse group of researchers for a year. We always allowed new participants to join at later sessions, following the co-creation principles of openness and diversity. However, only three out of 14 researchers attended every activity. Before each workshop, we proposed multiple dates to the potential participants, and we limited the workshop length to three hours to maximize the chances of participation. As it was discussed in the last interviews (see Section 4.7), the incorporation of new participants slowed the process. Both the goals and our overall progress seemed least clear to participants who attended the least, and the most committed participants considered that this situation was the main disadvantage of the process.

L4: Don't forget that co-creating is agreeing on the diversity of ideas. Most visualization designers are trained to figure out individually what the users need. In a co-creation process, it is important to remember that co-creating the outcome is everyone's mission and the ideas of the domain experts should not be easily discarded. Furthermore, agreement on the system requirements may be challenging due to the diversity of data and tasks across participants, as in our case. Although the goal is usually delivering a product that helps everyone, focusing only on features that everyone agrees on may not be good enough for each individual. Our participants recognized their influence on the outcome as a group, but did not recognize it as individuals. This may indicate that we did not correctly adapt to their diversity.

L5: Participation is not always perceived as an advantage. We believed that applying co-creation as a design method would satisfy the domain experts because it was an invitation to be involved. Following the co-creation principles of mutual learning, involvement and ownership, we organized multiple workshop activities to help participants expressing their needs and wishes. However, participants struggled with the method because they rather expected to get multiple finished solutions to choose from. Although some researchers later appreciated the method to collaboratively design the system, others did not.

L6: Mutual learning is not only about learning from the domain experts, but also about the experts learning from each other. In the interviews, participants agreed on that working together with their colleagues was the main benefit of the co-creation process. The workshops helped them to not only learn from each other, but also to refine their collaboration inside and outside of the workshops. One participant affirmed to not only have learned how to better present his own research, but also to correctly define what he truly needs to reach his research goals.

L7: In the academic context, early career researchers tend to focus on their individual goals. As social science researchers, the main goal of our domain experts was to publish their research. In the workshops, participants often expressed their focus on publishing and were mostly interested in how our collaboration could help them in that task. The topic of the doctoral students advancing on their dissertations came up often in the discussions about how the developed visualizations could help the researchers. Although every researcher knew that co-creating a visual information system for social science researchers was one of the goals of the project, senior researchers were more interested in co-creating the visualizations than junior researchers.

6. Conclusions

We presented a co-creation case study with 14 social science researchers to design a visual information system that supports their research tasks. We described the co-creation process together with the design requirements, and a first evaluation of the design method. We documented our experience and reflected on it to present the lessons we learned through this design study.

Participants felt listened to, and found the process useful to analyze their needs. They most valued learning about the topic of data visualization, and working together with their peers to learn from each other. However, participants had a hard time accepting the role of a co-creator, i.e. taking responsibility in the design process, instead of simply receiving a product. This led us to realize that participation and involvement are not necessarily perceived as benefits by the users. As co-creation and other participatory methods become more common in visualization design, it is important to reflect on the influence of the choice of method in the participants and in the outcome. Co-creation led us to a well-received product which participants perceived as the result of their collaborative design efforts. However, we struggled with participant commitment and a formal comparison with other methods is necessary to determine whether the time and effort needed in such an intensive design process is decisive for the user satisfaction and the long-term success of the system. Our work provides insights into the benefits and limitations of using co-creation as a visualization design methodology. Given that our sample size is small, however, the reliability of our findings should be validated with further experiments in future work. Furthermore, we worked in an academic environment and the findings may not necessarily translate to working in other environments or to collaborating with experts from other domains.

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