Related paper set: Supporting climate and data literacy in rural communities by incorporating authentic experiences in formal and informal settings

1. **Summary of set**

The best available science today indicates that today's children will be living in a world of rapid environmental change. Impacting food supplies, water resources, natural ecosystems, and human infrastructure, the magnitude of the change will depend upon the choices that they and we make (USGCRP, 2018). However, understanding the consequences of our choices requires understanding climate science, and this is a complex endeavor. Climate occurs across such scales of time and space, that it necessitates analyzing decades of data and scanning across multiple, simultaneous geographic scales. It requires analysis using multiple, complex representations of data, all with the ultimate goal of modeling possible futures. Yet the variability of local weather patterns in our daily lives, including extremely cold winters or mild summers in some locations may seem to contradict the decades of global patterns of warming. To understand climate, learners need to make sense of data concepts such as scale, variability, and trends in order to reconcile what seem to be contradictions. Climate can really only be investigated and understood through the lens of data (Shepardson et al, 2014; Shepardson et al, 2009). However, much current climate education focuses on understanding global earth systems or the differences between weather and climate, often leaving out the complexities or failing to integrate the data behind the current science.

The project described in this session is a multi-faceted effort involving informal educators, scientists, classroom teachers, exhibit designers, and researchers in utilizing NASA Earth systems data to build interactive learning experiences with authentic climate data. The effort we will describe integrates a field trip and classroom experience for 5th and 6th grade students from across the state of Maine and engages public audiences in conversation through expansion to science centers throughout New England. An essential aspiration of the project work is to understand—and create a model for—how educational materials that describe climate impacts in one place can be adapted for another. Therefore, this related paper set will describe the research on several components of the project, including findings from: (1) the development of a field trip experience that explores a local marine environment; (2) the development of classroom curricula that extent the field trip to explore ecosystems surrounding local school communities, (3) the testing and refinement of measures to describe students' data-literacy skills as they learn about climate; (4) students thinking about climate and data as a result of the integration of the field trip with classroom curricula; and (5) the development of climate and data focused interactive experiences in small science centers throughout New England.

This paper set strongly aligns with the theme of the 2021 NARST annual conference in its call for research to "empower, evoke, and revolutionize," and will therefore be of interest to NARST membership and enable strong contributions to the field. Taken together, the papers represent a novel approach to broadening climate science education in their collective reach to rural communities through authentic climate data experiences that build learners' understandings of scale and relationships between global phenomena and local ecosystems. In addition, the development and iteration of experiences in both formal classrooms and informal contexts will be of interest to NARST members and provide strong contributions for teaching and learning.

2. **Paper #1: Iterating a scientifically authentic data-rich informal learning experience to empower the next generation of climate stewards**

<u>Subject/Problem</u>

Despite significant commitment to climate change education among informal learning institutions, rich engagement with climate change dynamics *as represented by data* defies the kind of hands-on, place-based, experiential approach typical of informal learning environments. The result is a restriction in the ability of informal education to support the call in the NGSS (NGSS Lead States, 2013) to increase attention to both climate dynamics and data analysis and manipulation.

This paper describes one attempt to respond to this challenge. We describe the design, development, and iteration of a field trip experience as an exploration of the potential of informal learning environments to contribute to development of the data skills necessary for lifelong ecosystem stewardship. We discuss the evolution of key design features of the program through iterative cycles of formative evaluation and development. We describe the mechanisms created to connect the informal experience to the classroom (described in Paper #2) as a venue to continue data learning. We focus in particular on design choices that did and did not contribute to students' willingness and ability to manipulate and interpret data.

<u>Programmatic Context: Designing for Authentic Work with Data</u>

Launched in 2005 and run continuously since, [Name of Program] annually hosts over 70% of Maine's $5^{th}/6^{th}$ grade cohort in a 2.5 hour exploration of a local marine ecosystem. The program is continually updated to reflect current science being conducted by research scientists. A central design principle is authenticity, defined as students working in developmentally appropriate ways on current scientific problems using methods that mimic how scientists tackle those problems. Approximately 50 students per visit participate in hands-on and digital activities, working together in small groups of 4-5 and scaffolded by a 55-inch multi-touch table. The interface supports guided inquiry into a local marine ecosystem and the interactions of the range-expanding black sea bass, with Maine's iconic crustacean, the American lobster.

This paper will describe how the combination of the program's core commitment to authenticity, along with a central focus on climate change, led us to tackle the problem of authentic work with data and models in the informal learning environment. We will discuss the collaboration between scientists, data scientists, educators, exhibit designers, technologists, and researchers; the process of targeting and testing data learning outcomes; and the selection and execution of a compelling ecosystem narrative for learners. In particular, we will focus attention on the role of reflection during the experience, which emerged as a crucial element of student learning, and the creation of a digital Field Notebook to bridge the informal experience to companion work in classrooms.

<u>Iteration through Formative Evaluation</u>

Because pursuing data literacy through an informal learning experience was relatively uncharted territory, integrating researchers into an iterative design process, based on formative feedback, was essential to narrow the field of potential target outcomes and to understand students' engagement with data. Researchers collected data that included student focus groups and cognitive interviews, interviews with the informal educators, interviews and focus groups with classroom teachers, and observations. Researchers were challenged to simultaneously evaluate students' engagement in the experience, with climate science and with data, to decipher their relative impacts on observational findings in order to appropriately drive iteration. The paper will describe this process as well as samples of key findings such as:

- Pre-launch observations and interviews with students suggested the program's multi-touch table interface supported high levels of student engagement and collaboration, but could be leveraged further to achieve target learning outcomes. For example, shifting to a split-screen interface allowed student groups to divide into pairs, which allowed us to pursue the science and data literacy goal of peer review of findings.

- Post-launch, early observations revealed students' recollection of program content delivered by the two informal educators who staff each visit. This led to substantial iteration of the educator "script" to continuously emphasize both the role of data in science generally and the types of claims students make about the marine ecosystem based on data gathered during the experience.
- The program utilizes student reflection as an aid to learning. This takes the form of "annotations" of artifacts assembled during the experience as well as 60 second reflection videos recorded by students. All of these reflections are stored in a password-protected digital Field Notebook that is intended to bridge the experience to both home and classroom. Multiple cycles of observation and assessments by researchers supported refinement of those reflection moments to better support students using data as evidence of climate trends highlighted in the experience.
- Observations and data from student interviews and field notebooks revealed insights into students' articulation of their understandings, which led to revision to the interface prompts and scaffolding of students' experiences with the climate data.

The paper will connect the details of these design choices and refinements to the findings and analysis described in Papers 2 and 4.

<u>Promising Future Directions</u>

The paper will close with a discussion of promising directions for future research and iteration of the program to further enhance desired climate and data learning outcomes. Specifically, we will highlight the opportunity for:

- Research-guided refinements to the program's use of student reflection including supporting subsequent conversations about the experience (with peers, teachers, and parents) and scaffolding those conversations through use of the artifacts collected in the Field Notebook (Pagano et. al., 2019, 2020); and
- Continued focus and refinement of mechanisms, routines, and resources that connect the formal and informal learning environments.
- Research regarding students' data moves as indicators of their thinking as they progress from examining small data sets through large data sets collected across time and geography.

3. Paper 2: Developing data- and climate-focused classroom curriculum

<u>Subject/Problem</u>

Today's most urgent questions and opportunities to innovate demand (1) a strong STEM workforce equipped with the expertise necessary to address complex problems, and (2) a society with the disposition, knowledge, and skills to be informed decision-makers and consumers of information. As reliance on information technology increases in all aspects of life, our future professional and personal success will depend largely on our ability to derive information from data. The potential for rapidly expanding access to data to transform how we live and work is widely recognized (Casserly, 2012; Eagan et al., 2014; Hart Research Associates, 2013). However, we are still learning how to help people develop the skills necessary to seek out, manage, and make meaning from those data—skills collectively referred to as *data literacy.* While data *skills* have historically been taught in isolation in mathematics classes, data *literacy* lies at the intersection of science, mathematics, and computer science. Recent shifts toward a more integrated approach call for work with authentic data in science education (e.g., NGA & CCSSO, 2010; NGSS Lead States, 2013), but there is still a need to establish empirically supported curriculum and instructional approaches, particularly in the early grades.

The program described in this paper provides a unique setting in which to begin the process of engaging students with authentic science data as they explore the impacts of climate change on a local marine ecosystem. The work described in this paper uses the field trip visit to the informal science institution as a jumping-off point for additional classroom-based learning experiences.

Design/Procedures

The classroom curriculum consists of a series of interconnected learning modules which extend and build upon the work students began during their field trip experience, using authentic science data to explore the impacts of climate change on their own regional ecosystems. These modules begin with a recap, which uses their virtual field notebook to remind them of the work they did, with a focus on the data they used and the analyses they conducted.

From there, they proceed to two data-focused lessons, which introduce students to a new set of tools, including Concord Consortium's Common Online Data Analysis Platform (CODAP) and Sage Modeler, which they will use throughout the curriculum to visualize, analyze, and make meaning from science data. These lessons allow students to practice some of the basic data skills they will use in other explorations – calculating a mean, sorting and filtering a dataset, creating and analyzing scatter plots, and identifying and describing trends in a dataset.

After completing these two lessons, students can complete one or more ecosystem modules, based on their location or interests. Topics for these modules include Ticks and Lyme disease (Forest Ecosystem), Canada Lynx (Forest Ecosystem); Wild Blueberries and Aroostook Potatoes (Field Ecosystem), Lake Ice-Out and Loons (Freshwater Ecosystem) and Lobsters & Black Sea Bass and Right Whales in Trouble (Marine Ecosystem).

Each module was developed using authentic science data, often in collaboration with the science researchers who collected it. The modules consist of a narrative arc which plays out over multiple class periods. They begin by engaging students' interest through a story or question, and proceed from day to day through various activities, typically involving one or more datasets and analyses, which drive the storyline forward. Each module culminates in a final synthesizing activity such as designing a public service announcement, creating a poster, or making a data-based recommendation to local government about actions to be taken.

Analysis & Findings

Modules were tested in classrooms during the 2018-2019 and 2019-2020 school years, as described in Paper 4 of this session. In addition to providing information about student data skills, attitudes about climate change and science, and interest in science careers, the work of the evaluation and research team helped inform our approach to curriculum design and delivery. This iterative process focused on three key areas:

- Content – Was the material at an accessible level for the students? Although we knew that we would be "pushing" students to participate in activities that might be considered "advanced" (e.g., conducting linear regressions on scatter plot graphs!), we wanted to make sure that these activities were sufficiently scaffolded, both in terms of student instruction within the activity as well as in teacher supporting materials, so they could comfortably navigate the materials.

- Delivery – Over the course of testing the curriculum we tried several different strategies for delivering the key components for students to use, including written student instructions, interactive data visualization/analysis tools, questions to focus student attention and check for understanding, and final, assessable work assignments to be turned in to the instructor and graded.
- Instructor supports – Each module includes teacher guides for each lesson within it. These guides provide a lesson overview, estimated time to complete, target student learning outcomes, alignment to standards, vocabulary terms, materials and technology requirements, and suggestions about preparing for and facilitating the lesson.

Working closely with our research and evaluation team, we used feedback from teachers and students to make ongoing modifications to the curriculum content and instructor supports. This feedback also helped to shape our strategies in building the online lessons for each module, which were finally created in Concord Consortium's "Lightweight Activities Runtime and Authoring" (LARA) system, which was piloted for classroom use in fall, 2019. This Web-based approach turned out to be especially valuable in spring of 2020, when all instruction was shifted to online delivery. Because the classroom curriculum was already designed for online use, we were able to continue with development, testing, and refinement throughout the remainder of the project.

4. Paper 3: Got Data? Developing an online, choice-based assessment of data literacy skills

<u>Subject/Problem</u>

Educators aim to equip their students with the knowledge and skills they need to move forward as confident and independent learners in the world. As a society, investment into assessing how learners progress is essential. This paper focuses on a piece of the assessment puzzle that rests outside the frame of standardized achievement tests – understanding how and if students transfer their learned skills and disciplinary practices into solving new problems.

We introduce a measurement tool called *choice-based assessments* (CBAs; Authors, 2013). CBAs are interactive technologies grounded in the theoretical framework of preparation for future learning assessments (Author, 1998), which afford students opportunities to learn during the evaluation. CBAs are frequently designed as short, online games, making them ideal vehicles to cross between formal and informal environments (Authors, 2019; Authors, 2016). By design, CBAs are goal-based and provide manifold opportunities for exploration. By embedding learning resources within the environment, CBAs can not only gather information on students' mastery of content, but also capture students' choices during exploration, thus providing insight into their use of disciplinary practices and learning skills. By separating content mastery from learning behaviors, CBAs can provide a more nuanced view of student growth.

Here we present the development of a new CBA that targets students' willingness and ability to manipulate and interpret data. We discuss its implementation in two studies with students who engage in [Name of Program] and its accompanying curricula (see Papers 1 and 2), as well as the triangulation of the CBA measures with other measures of data literacy used in the studies (see Paper 4).

Design/Procedures

Assessment Environment: The premise of Datalet is that the student is a new fact-checker for a local newspaper and must submit summary reports to their editor. For each of three levels, students have a claim they must investigate and data they can explore (Figure 1, panel A). The game tracks their choices around engaging with the data as they determine if a claimed pattern exists. Students also can annotate the data in their report to the editor (Figure 1, panel B).

Study Design and Participants: Two studies were conducted in the 2019-2020 academic year. Participants in both studies were 5th and 6th grade students from 22 elementary or middle school classrooms in the Northeastern U.S. (total N=469). Study 1 was a pilot with N_1=166 students with logfile data from the game completed after the learning experience; a subset of 140 students also had complete pre and post data from student questionnaires (see Paper 4). Study 2 was intended as a pre-post administration of Datalet, but was interrupted by COVID-19, resulting in N_2=303 logfiles from students who played the game prior to the learning experience; 61 individuals also had pre scores from the student questionnaire. Teachers administered all assessments in both studies, following a script provided by the research team. Students were to play independently, without intervention from other students or the teacher. Students played an average of 18.7 min (SD=8.9).

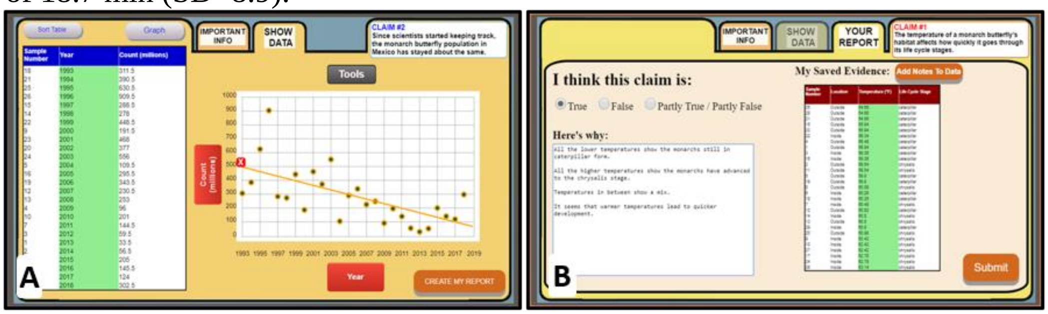

Figure 1. Main Interaction Windows for Datalet: A) Data Exploration: Students view a data table and have the options to hover over (highlight) specific data points, sort, and/or graph the data. There are also tools to plot reference and trend lines. **B)** Claim-Evidence Report: After exploring the data, players choose if they think the claim is true, false, or other and provide a text justification to the editor.

Process and Learning Measures: Process behaviors used to assess data literacy skills included numbers of hovers, table sorts, graphs plotted (including reference or trend lines) and variables sorted on or plotted. In-game learning measures included the *Quality of Evidence* scores, based on the final tables and plots students submitted (i.e., did students sort and graph relevant variables). In addition, *Claim Explanations* scores from student reports were achieved by coding for various data-centered characteristics, e.g., Noted Correct Trend, Noted Variability in Data.

Analysis & Findings

Analyses presented in the paper will include summary statistics of the major data moves that students exhibit in the game and correlational analyses of the data moves with both in-game and the student questionnaire learning measures. Preliminary findings indicate:

Data moves in the game correlate significantly with both in-game and student questionnaire learning measures, e.g., the number of times students sort their data correlates with their *Quality of Evidence* scores (τ's from .36 to .81, $p<.0001$), their *Claim Explanation* scores (τ=.15, $p<.001$) and their questionnaire post scores (τ=.21, $p< .001$).

In-game learning measures correlate significantly with student questionnaire learning measures and science interest, e.g., *Claim Explanation* scores correlate with pre- and post-questionnaire data literacy scores (τ=.28 and τ=.34, respectively, p's<.001) and with pre- and post-science interest scores (τ=.19 and τ=.17, respectively, p's <.002).
Comparison of in-game learning measures for Study 1 vs Study 2**:** "Pre" students who played Datalet *prior* to their learning experience (Study 2) vs. "Post" students who played Datalet *after* (Study 1) show no significant difference in *Claim Explanation* scores for Level 1 (p=.131). Level 1 was a "simpler" claim in that only sorting was available as a data analysis tool. However, Post students performed significantly better for Level 2 than their Pre counterparts (p=.010). Claim 2 provided both sorting and graphing tools. Interestingly, Pre students took significantly longer to answer both claims; Level 1 mean duration: Pre = 10.8 min, Post = 7.9 min, p = .000; Level 2 mean duration: Pre: 4.8 min, Post = 4.3 min, p = .031).

Analyses of process and learning measures are ongoing, however these preliminary findings indicate Datalet is a promising tool to illuminate student growth in data skills and dispositions.

5. Paper 4: Supporting student learning and interest in climate and data through a formal-informal connection

Subject/Problem

Multiple studies have shown that students interest and engagement in science wanes around the time they get to middle school (Ali, et al., 2013; Osborne, Simon, & Collins, 2003; Tai, Liu, Maltese & Fan, 2006). One proposed approach for improving student science learning is an ecosystem perspective, which provides learning experiences through the diverse, multiple contexts that make up a learner's community (Traphagen & Traill, 2014). This is reinforced by research that suggests experiences in informal out-of-school contexts can have powerful positive impacts on STEM engagement (National Research Council, 2009; Falk & Dierking, 2010).

The research in this paper will describe the findings about implementation and student outcomes that resulted from a suite of science learning experiences connecting informal and formal learning environments. These experiences translated information from NASA's atmosphere and ocean data sets into interactive, technology-based, data-intensive science activities. The data-intensive approach is responsive to the emphasis on science and engineering practices highlighted in the Next Generation Science Standards (NGSS).

The suite of activities included a 2.5 hour informal educational experience at a science center and research institute, during which 5th and 6th grade students complete a variety of climate and data-focused activities. The activities at the science center focused on local species and climate data, evidence of and connections between local and global climate change, and the ways human activity intersects with climate. The experience was led by staff at the science center, and included stories about professionals associated with the center. During the experience, students work in teams on an interactive touch table and reflect on their experiences in a field notebook that captures some of the data artifacts and video reflections that students generated. Back in the classroom, teachers implemented at least 3 related classroom modules within the next two months. During the first classroom module, students looked at evidence and artifacts in their field notebook, connecting their work in the informal setting to their classroom work. The two additional modules built on the content of their informal experience and focused on using climate data to better understand and predict local species changes over time.

Design/Procedure

Multiple types of data were collected from students and teachers. This paper focuses on understanding students' learning and thinking based on data from the field notebook and paper and pencil questionnaires. Qualitative data from teacher interviews and feedback questionnaires provided additional insight into the variability in teacher implementation of classroom curricula.

Over 260 students in grades five and six completed the paper and pencil questionnaires in their classrooms prior to the experience at the science center and after completion of the three classroom modules. The questionnaires contained items and scales adapted from previously developed measures of middle schools skills related to interpreting data (Authors, 2020), attitudes and beliefs about climate (Christensen & Knezek, 2015) and attitudes toward science (Weinburgh & Steele, 2000). Items were pilot tested and revised in the previous year of the project. The four constructs included in the questionnaires were: (1) student data skills (11 items); (2) student climate change beliefs (10 items); (3) student attitudes toward science (15 items); (4) students interest in specific science careers (7 career items). We tested the internal consistency for the items related to the first three constructs; average Cronbach's alphas for the pre and post measures were between 0.71-0.91.

Analysis and Findings

The full paper will describe preliminary findings related to the field notebook and the student questionnaires, and will include insights based on variation in teacher implementation. Data from the field notebook, in particular video reflections, provide evidence of students' use of scientific data during the science center field trip, including students' claims about changes in local ecosystems, and their successes and challenges in articulating connections between local ecosystem dynamics and global climate change. Findings from the student questionnaire indicate that the suite of data-intensive climate science experiences spanning both informal and formal learning environments was associated with significant increases in data skills (increase from 50.5% correct to 67.2% correct, $t(280) = 15.9$, $p < 0.001$) and in students' climate change attitudes and beliefs (3.44 to 3.66 on a scale of 1 to 5, $t(261) = 5.96$, $p < 0.001$). During the same time period, students' interest in being an environmental scientist significantly decreased (2.11 to 1.97 on a scale of 1 to 4, $t(263) = 2.60$, $p = 0.01$), and students' overall interest in science also decreased slightly (3.17 to 3.03 on a scale of 1 to 5, $t(267) = 4.67$, $p < 0.001$). On all scales, changes in scores did not differ by grade or by student gender. Finally, the variation in teachers' implementation of curricula, including four teachers' choices to implement two lessons prior to the field trip and some teachers' decisions to use whole class discussion and reflection, provides insights into the ways in which teachers may have further reinforced students' understandings.

These findings have implications for climate science education in that they demonstrate middle grades students use of data to develop understandings about climate. Further, they demonstrate the learning that results from reinforcing informal learning in the formal classroom context. They also highlight the need for further research on students' interest in science and the relationship between teachers' implementation of curriculum and student learning and interest.

6. Paper 5: Building a data-focused science center community of practice

Background

One of the goals of [Name of project] is to build the capacity of small science centers serving rural and small city audiences to provide meaningful science learning experiences related to climate and data literacy. Small and medium-sized informal science institutions (< 50,000 square feet) are uniquely positioned to reach students regarding issues of climate change and data literacy since they are sometimes the only out-of-school resource serving the community and they typically are focused on delivering a place-based experience.

Over five years the project team developed and implemented: (1) three data literacy activities that were intended to be implemented either as off-site events facilitated by museum educators or on site as an in-museum workshop (By the Numbers; Ticks Up Close; and Weather, Climate & You); (2) an exhibit prototype engaging visitors with data related to weather and climate; and (3) a regional Community of Practice of informal science center educators and program developers engaged in climate and data literacy. In this paper, we will describe the effort to design, iterate, and research these efforts to understand the successes and challenges of engaging learners in experiences about climate and data literacy through science centers.

Design/Procedure

Participants in the study included 15 science center staff from 11 science center partner sites. Science center partners were interviewed annually to understand their perspectives on the features of their implementation of project activities, development of the science center community of practice, and their overall experience in the project. Science center partners were also asked to complete an online form each time they implemented a project-designed activity and describe who they implemented the activity with, how they implemented the activity, and what aspects of the activity went particularly well or not well. A member of the research team also attended the annual in-person project meetings and the monthly virtual meetings with science centers partners in order to monitor progress and share formative findings.

Selected Findings

Eight of the 11 science center partners had implemented project activities in some form by June 2020. The three centers that had not implemented RWRS activities had planned to do so in spring 2020, but their facilities closed to visitors in response to the COVID-19 pandemic.

Partners reported that the activities were engaging for students and their families. Some partners indicated that it was a challenge to communicate data literacy concepts in a meaningful or deep way to their visitors, especially given the limited time they typically interact with visitors. In particular, the tick programming activity was reported as engaging for science center audiences, in part due to the regional public health concern about the prevalence of Lyme disease; however, the connection between the tick activity and climate and climate data is complex and needed to be strengthened.

Several science centers were interested in adapting the activities to an online learning format or adapting the hands-on aspects of the education experience where hands-on activities are not possible in-person. A few science center partners suggested findings ways to link the pandemic to data literacy and climate change.

A primary findings focused on the support enabled by the community of practice that emerged and evolved over the course of the five years of the project. Partners valued the connections with other, similar-sized science centers in their region, particularly the in-person meetings, which were held once a year. During the final year of the project, partly in response to the COVID-19 pandemic, the group began meeting monthly via Zoom.

Many of the science center partners said the project activities dovetailed with their centers' missions and/or increasing interest in promoting climate literacy. The project has also had a ripple effects on some science center partners, allowing them to promote the desire to promote data and climate literacy with their colleagues and their visitors. For example, two partners leveraged their involvement in the project to push their institutions to incorporate more science and climate change in the design of their exhibits and visitor experiences. In addition, one partner was inspired to create their own community of practice of science museums and nature centers in their region.

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