Promoting Reflection and Interpretation in Education: Curating Rich Bookmarks as Information Composition

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ABSTRACT
Reflection, interpretation, and curation play key roles in learning, creativity, and problem solving. *Reflection* means looking back and forward among building blocks constituting a space of ideas, contextualizing with processes including tasks, activities, and one's internal thinking and meditating, and deriving new understandings, known as *interpretation*s. *Curation*, in the digital age, means searching, gathering, collecting, organizing, designing, reflecting on, and interpreting information.

We introduce *rich bookmarks*, representations of key ideas from documents as navigable links that integrate visual clippings and rich semantic metadata. We support curating rich bookmarks as *information composition*. In this holistic visual form, curators express relationships among curated elements through implicit visual features, such as spatial position, color, and translucence.

We investigated the situated context of a university course, engaging educators in iterative co-design. Rich bookmarks emerged in the process, motivating changes in pedagogy and software. Changes provoked students to collect more novel and varied ideas. They reported that curating rich bookmarks as information composition helped them reflect, transforming prior ideas into new ones. The visual component of rich bookmarks was found to support multiple interpretations; the semantic to support associational exploration of related ideas.

Author Keywords
reflection, interpretation, curation, visual semantics

ACM Classification Keywords
H.5.m Information Interfaces and Presentation (e.g. HCI): Miscellaneous

General Terms
Human Factors, Design

INTRODUCTION
Creative endeavors, such as problem solving, scientific research, art, and learning, benefit from reflection and interpretation. We learn through reflective problem solving, seeking schemas and metaphors to build coherent, meaningful interpretations [21]. We *reflect*, looking over the building blocks that constitute a space of ideas, contextualizing with processes including tasks, activities, and one's internal thinking and meditating, and deriving new understanding, known as *interpretation* [26]. We reflect on interpretations, constructing relationships that connect ideas.

Curation now popularly means the process of searching the Internet and digital repositories, collecting information, organizing that information in meaningful ways, reflecting on collected information, and interpreting that information to form new understanding. This growing wealth of information makes curation valuable for innovation, entrepreneurship, and education [24]. Novel representations for curation, such as Pinterest, have become popular [10]. In education, students engage in curation tasks involving divergent thinking, answering open-ended problems including developing a final project idea or planning a student organization event.

New representations are needed to help students perform curation tasks. Illich described a propensity of society to create "industrial" tools that enforce convergent ideas and methods specified by their designer rather than *convivial* tools, which promote divergent thinking, enabling the user to "enrich the environment with the fruits of his or her vision" [15].

We introduce the *rich bookmark*, a navigable link to a web document. A rich bookmark integrates (1) a visual clipping from a document and (2) automatically extracted detailed metadata that concisely captures essential meaning, such as a book and its authors, a product, its price and related bestsellers, and a scholarly article and its references and citations (see Figure 1). A rich bookmark is a unit of meaning that a human curates to represent what matters in context, the key ideas involved with the task at hand. The visual clipping provides a concise representation that affords organization within a collection and supports flexible and ambiguous interpretations, helpful in promoting divergent thinking with convivial tools. The metadata explicitly provides details, relationships, and context for reflection.

Figure 1: An information composition of a innovative hybrid ergonomic vacuum cleaner-duster created by student U13 for her final assignment in DPCE. Metadata is shown for a rich bookmark with a text clipping from a Wikipedia article on velcro. Wikipedia categories are navigable: clicking opens the associated web page in the browser, which can stimulate reflection on related ideas. This rich bookmark on velcro is juxtaposed with others about vacuums and back pain.

Our InfoComposer tool supports creating rich bookmarks, and curating a collection of them as *information composition* [32], a holistic visual and semantic representation of an information collection (see Figure 1). Relationships are expressed by manipulating implicit features of rich bookmark visuals, such as spatial positioning, size, color, and translucence. InfoComposer is a convivial tool where individual creative freedoms are realized through the curation of rich bookmarks and their implicit organization as information composition.

We conducted a new field study in the undergraduate course, The Design Process: Creativity and Entrepreneurship (DPCE). We engaged with educators and students in iterative co-design cycles. Rich bookmarks emerged in pedagogy and software. *We hypothesize that the introduction of rich bookmarks in pedagogy and software promotes reflection and interpretation.* Findings show that when rich bookmarks were introduced, students collected more novel and varied ideas. Students reported looking at the integrated metadata of rich bookmarks, reflecting upon collected information, forming new interpretations, and generating new ideas.

We begin with a survey of prior work on reflection and interpretation, visual representations, and curation. We then describe how to curate rich bookmarks as information composition using InfoComposer. Next, we present a field study, developing quantitative and qualitative findings. Implications for designing software tools and course curricula to promote reflection and interpretation are derived. We conclude by advancing research contributions.

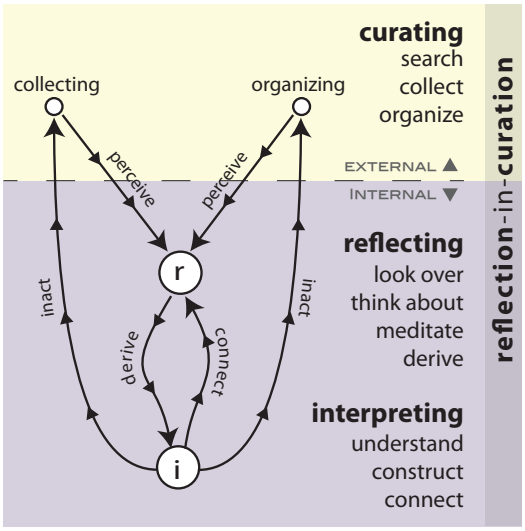

Figure 2: Reflection-in-curation processes and experiences diagram. Collecting and organizing processes involve iterative cycles of reflection and interpretation, helping a person decides what to collect and imagines how collected ideas are connected to each other.

PRIOR WORK

We ground our work in prior literature on reflection and interpretation. Integrated visual and semantic components of rich bookmarks and information composition differentiate our work from prior representations. We address the importance of digital curation and limitations of prior tools.

Reflection-in-Action → Reflection-in-Curation

Reflection and interpretation are key in cognitive processes of divergent thinking [26], and thus, curation. A person engages in reflection, thinking about what is important and meditating on ideas. Related ideas are connected, mental models constructed, and interpretations derived. Reflection can surface through doing. Schön calls this *reflection-in-action* [26]. New interpretations emerge, are critiqued and restructured through reflection, and then converted into action. When these actions involve collecting and organizing information amidst curatorial processes, we call this *reflection-in-curation* (see Figure 2). Collecting and organizing emerge through iterative cycles of reflection and interpretation over time.

Interpretation is rooted in perception [14]. Thus, the rich bookmark visual plays an important role in how represented ideas are interpreted. Merleau-Ponty argues that interpretation is not objective, but instead derived through reflection of a subjective sensory experience [20]. Subjective interpretations can be ambiguous, which can aid creative design [13]. The rich bookmark visual supports multiple interpretations that can change and evolve through curation of other rich bookmarks. As interpretations are generalized across experiences, connections, categorizations, and orderings are constructed [12]. *We hypothesize that curating rich bookmarks as information composition helps one perceive connections among ideas through comparison of visual qualities and semantic relationships, and form categorizations and orderings through the process of forming an integrated representation.*

Support for Reflection and Interpretation

Both reflection over time and reflection-in-action have been investigated in education and HCI contexts, but no one to our knowledge has investigated reflection-in-curation. Beale found that learning improves when students author blogs as a medium for reflecting on what they learned [3]. We envision improved learning experiences for students who curate information compositions of rich bookmarks on course topics. Sharmin and Bailey found that designers reflected using their own artifacts and related artifacts to relive experiences [28]. Rich bookmarks can operate as artifacts for reflection. Search Dashboard improved search performance by supporting reflection on personal search habits [2]. We support reflection on prior collected ideas through the visual representation of rich bookmarks and information composition.

Creative tasks benefit from flexible representations that support reflection [22, 11]. Lightly constrained representations are key for externalizing ideas, such as music scores [11]. Representations using implicit visual features, such as spatial positioning, promote divergence in early design tasks by minimizing structural commitment [22]. Information compositions of rich bookmarks are flexible representations, in which ideas are externalized through rich bookmarks and their implicit visual relationships. Interpretations arise and are reflected upon as rich bookmarks are collected and organized.

Visual Semantic Representations

Prior research has investigated how visual representations of semantic information help people understand and collect. Spatial hypertext used two-dimensional position to represent relationships between ideas, articulating the need for informal structure in knowledge representations [18]. A *surrogate* is a representation of an information resource that enables access to it [6]. A rich bookmark is a type of surrogate that integrates visual clippings and detailed metadata. Woodruff et al developed enhanced thumbnails, combining image thumbnails and textual summaries to represent web page surrogates [33]. Enhanced thumbnails use visual representations, but lack rich metadata. Teevan et al developed visual snippets, computationally generated summaries of document contents designed to support recall [30]. While similar, rich bookmarks represent specific ideas from documents, integrating human curated clippings and extracted metadata.

Kerne et al [17] and Webb [32] used information composition to represent collections. They investigated mixed-initiative approaches to collecting search result surrogates as information composition, where computational agents search, collect, and visually organize surrogates. The present research builds upon this, but eschews computational agents, in order to more directly investigate reflection and interpretation in human curation. We add support for referential graphs of nested entities in metadata, improving its associationality and richness.

Freed supports users reflecting on and organizing personal visual media collections [19]. Freed allows multiple perspectives on the same collection.While connected navigational

Figure 3: Information composition for the *Chameleon Watch* soft innovation created by student U107 in DPCE. Rich bookmarks about fashion, biology, and chemistry were juxtaposed and blended. The emergent novel idea: a watch that always matches the wearer's outfit.

node-link diagrams are featured, Freed does not support automatic extraction of metadata, nor is it designed to specific ideas from Web documents.

Curation

Curation has grown popular as nomenclature to describe meaningful collection of digital media. Rosenbaum distinguishes curation from aggregation by the human decision in collecting each item [24]. Pinterest is a social media service, enabling users to build collections of bookmarks using visual surrogates, known as 'pins', which are organized in pinboards [23]. Zarro et al find that pins support flexible interpretation, where users can recontextualize images curated by others through repinning [34]. Pins extract title, but unlike rich bookmarks, lack detailed metadata. Pinboards do not enable flexible visual structures, which aid creative reflection [22, 11] and conviviality [15].

CURATING RICH BOOKMARKS

InfoComposer is a new creativity support tool for collecting rich bookmarks and organizing them as information composition. It is a web application, presently consisting of a JavaWeb Start program in tandem with a Firefox extension.

Collecting Rich Bookmarks

A curator collects a rich bookmark by dragging and dropping a representative image or text clipping from a source document in a web browser to a position within an information composition. A curator engages reflection and interpretation in creatively choosing what clipping to collect. InfoComposer automatically extracts metadata from the source document. A rich bookmark is formed through the integration of the visual clipping and metadata.

InfoComposer derives intricate, associational metadata for information types including books, consumer products, movies, and art using *meta-metadata*: an open-source framework for authoring wrappers which define metadata structure, extraction rules, performed operations, and presentation guidelines for heterogeneous information sources [16]. Present meta-metadata wrappers derive metadata from sources including Wikipedia, Google Patents, Amazon, Flickr, and YouTube.

We extend *in-context metadata details-on-demand* (see Figure 1), a fluid interface for visualization of hierarchical metadata structure [32]. This interface appears after a short timeout while hovering over a rich bookmark. *We hypothesize that metadata will expose curators to related information, helping them reflect and form interpretations that, in turn, motivate new searches and inspire changes in prior ideas.*

Organizing Rich Bookmarks

Curators meaningfully organize rich bookmarks to express ideas. Organization is rooted in seeing relationships among collected ideas through reflection and interpretation. Relationships are expressed through manipulating implicit visual features of rich bookmarks in an information composition [32, 17]. Manipulations engage reflection-in-curation, such as emergence of a new idea from spatial juxtaposition of two rich bookmarks previously thought unrelated (see Figure 3).

Information composition enables visual layering [31] of ideas. Curators differentiate emphasis on ideas in a composition by resizing rich bookmarks. They style text, creating layers by choosing font families, faces, weights, sizes, and colors. Curators develop exposition of ideas by authoring text annotations as and labeling groups.

Curators position rich bookmarks spatially, allowing gestalt groupings of ideas to emerge through proximity. Enhanced juxtaposition is supported by *blending*. InfoComposer enables representing connections and discovering emergent relationships among source materials by overlapping rich bookmarks, and then blending ideas visually by manipulating the translucence of overlapping border areas (see Figure 3).

FIELD STUDY IN EDUCATION

Evaluating impact in the situated context of a classroom, outside of controlled laboratory settings, is challenging. Designers must work closely with educators to ensure that consistently enabling meaningful learning experiences for students is prioritized [5, 9]. Investigations are extended, spanning long periods of time and requiring iterative cycles of refinement [8]. Aspects of the classroom environment, such as curriculum, assignments, and technological tools, form a systematic whole, in which changes in one result in simultaneous changes in the others [5]. The following field study in education addresses these challenges, evaluating the effects of not only rich bookmarks and InfoComposer, but also pedagogy.

We conducted a field study in *The Design Process: Creativity and Entrepreneurship*, an interdisciplinary undergraduate course. Students are assigned to design *soft innovations*: new ideas derived by combining and transforming. As part of this process, students curate prior work collections of needs, resources, and precedents. Students are required to search the Internet and patent repositories in order to find and collect relevant information for a prior work collection. They reflect to innovate new processes, products, or services.

The study occurred over two semesters with two distinct sets of students. In each semester, students curated prior work collections as information compositions for their soft innovations. We collaborated with the course instructor in iterative design and development of pedagogy – assignment documents and in-class presentations – and conjointly on InfoComposer to better support engaging students in curation of rich bookmarks. We collected information compositions from 85 students in the first semester and from 123 different students in the second.

First Semester (S1): Curating Surrogates

In S1, curation elements within InfoComposer were called image and text 'surrogates'. Techniques for collecting and organizing surrogates were identical to those presented in the previous section for curating rich bookmarks.

We gave a presentation on how to use InfoComposer for the assignment. We demonstrated features of the software, authoring a semi-completed information composition. We provided help documentation. Grading was participatory.

Second Semester (S2): Curating Rich Bookmarks

We observed that many students failed to collect 'surrogates' in S1, instead composing visual clippings without links to source documents. We hypothesized that this failure was related to difficulty understanding the abstract concept of 'surrogates'. In S2, we introduced the concept of 'rich bookmark' in pedagogy and software, in lieu of 'surrogates'.

Pedagogy with Rich Bookmarks

We presented rich bookmarks to students as visual and semantic units of meaning, useful for curating, expressing, and connecting ideas. We gave a presentation in class on the conceptual basis and functional use of InfoComposer, rich bookmarks, and information composition. We gave students video and hypertext documentation about rich bookmarks and how to collect them in InfoComposer, along with a list of grading metrics, explained through scored example compositions.

Students used InfoComposer for two assignments: an introductory curation task to gain experience with the tool, and the course final. In the introduction, students were asked to curate coherent information compositions in which they imagined their perfect: vacation, home, personal robot, college experience, or social media service. The assignment was designed to teach curating rich bookmarks as information composition through an engaging and fun task. For the final, each student was asked to curate three prior work collections as information composition, one for each of three soft innovations s/he had previously created.

We graded introductory assignments using a set of prior holistic creative ideation metrics [32, 17]: Emergence, Visual Presentation, Relevance, and Exposition. Students received feedback on their performance. By evaluating students' products with ideation metrics, we stimulated them to understand, learn about, and engage in creative processes. We were unable to use these holistic metrics to evaluate the final assignment, because they presently require raters, and the number of compositions was larger than we could manage (519).

We introduced a new evaluation metric, *Rich Bookmark Variety*, to measure how a student has created rich bookmarks from a variety of sources and concepts. Criteria are:

- At least 75% of collected clippings are rich bookmarks.
- Rich bookmarks link to a variety of websites.
- Linked web pages are about variety of ideas or concepts.

The first two criteria were computed (See [32] for how to compute Variety.); the third was performed by a human rater.

Supporting Rich Bookmarks in InfoComposer

The introduction of rich bookmarks motivated several changes to software. We added a broken link visual affordance to differentiate unlinked clippings from rich bookmarks. We improved metadata extraction and visualization, providing more semantic details in rich bookmarks.

Due to limits of our Firefox extension, occasionally the source document link is missing after dropping. An *unlinked clipping* is created, instead of a rich bookmark. We indicate an unlinked clipping by adding a broken link icon in the top right corner of the visual (see right). The broken link icon was designed to provoke students to transform the unlinked clipping into a rich bookmark, which is accomplished by dragging the source document's address from the web browser onto the clipping.

We improved richness of metadata associated with rich bookmarks to include graph data structures involving nested entities (e.g. references and citations for scholarly articles). In-context metadata details-on-demand initially presents nested entities collapsed; they can be expanded to support drilling down through connections. Metadata for connected documents are extracted on expansion, allowing exploration of connected ideas. Students can engage in fluid citation chaining, expanding the graph of citations for a scholarly article, navigating to citations, and collecting new rich bookmarks.

Data and Analysis: Methods

We hypothesize that the rich bookmark, manifested as interactive artifact, pedagogy, and software, promotes reflection and interpretation on student assignments, leading to more creative products. We develop a mixed methods evaluation, using the information compositions created by students and self-reports as sources of data for investigating reflection and interpretation. We investigate effects of changes to pedagogy and software features on creativity through quantitative ideation metrics [32, 17]. In the second semester, we collected student experience reports. Without significant changes to pedagogy or software, we asked students in a third

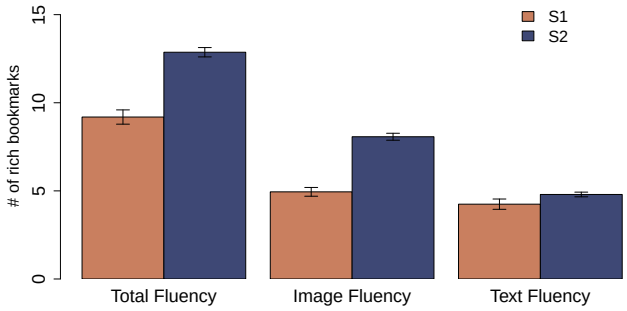

Figure 4: Mean Fluency scores for students' information compositions on final assignment, separated by semester.

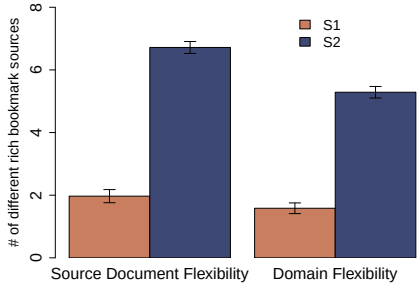

Figure 5: Mean Flexibility scores, in number of information sources, for students' information compositions.

semester more directed questions about the use of metadata and how specific curation activities effected ideas.

Ideation Metrics: Measuring Creativity Between Semesters

Each rich bookmark is the product of reflecting on, collecting, and interpreting an idea from a source document. Prior research developed metrics for evaluating individual ideas in engineering design [27] and curation tasks [17]. We likewise evaluated the creativity of students' ideas with elemental ideation metrics: Fluency, Flexibility, and Novelty. *Novelty* is the uniqueness of ideas. *Flexibility* is diversity of ideas. *Fluency* is quantity of ideas. Novelty and Flexibility are computed across two levels of granularity: source documents and top-level web domains. Novelty is additionally calculated in terms of image clippings. Fluency is computed for all elements, and separately for images and text.

Ideation metrics were computed as in prior work, except for Image Novelty. Novelty is the inverse of the frequency of an idea across all information compositions authored in an experiment, similar to how inverse document frequency (IDF) is computed in information retrieval. In previous controlled laboratory experiments, the corpus of collectable images and documents was constrained by fixed search queries. Students in our study can collect from any information source. As a result, many images appear in only one information composition, giving an Image Novelty score of 1 for many images.

We introduce a new Image Novelty metric based on the popularity of images through search results. This produces a granular distribution of Novelty scores. For each image, a Google image search is performed using the image as the query. The number of search results determines popularity (i_n). We take the sum of the logarithms of the popularity of images from all compositions to derive average popularity ($\bar{c}$). We then double average popularity ($\bar{c}$) to estimate a maximum, and calculate the normalized Image Novelty (*inov*) of a composition (C_k), where novelty is the inverse of popularity.

$$\bar{c} = \frac{\sum_{\forall i \varepsilon C} log(i_n)}{\|i \varepsilon C\|} \quad (1)$$

$$inov(C_k) = \frac{\sum_{i \varepsilon C_k} 1 - \max(1, \frac{\log i_n}{2 \cdot \bar{c}})}{\|i \varepsilon C_k\|} \quad (2)$$

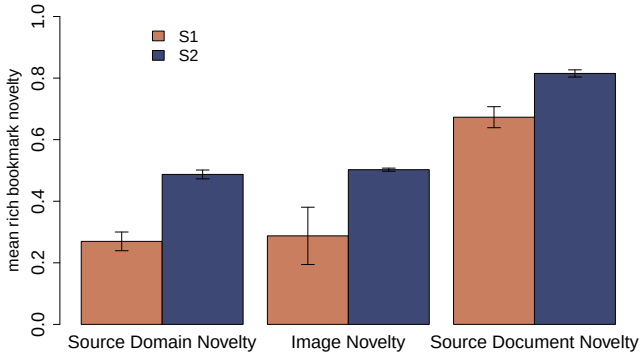

Figure 6: Mean Novelty scores for students' information compositions on final assignment, separated by semester.

Elemental Ideation Metric	S1 μ	S2 μ	W	$p <$
Total Fluency	9.19	12.87	59167	.001
Image Fluency	4.94	8.07	61629	.001
Text Fluency	4.25	4.80	48080.5	.008
Source Document Flexibility	1.97	6.72	72074	.001
Domain Flexibility	1.58	5.29	69110.5	.001
Source Domain Novelty	.270	.487	28625.5	.001
Source Document Novelty	.673	.815	27794.5	.001
Image Novelty	.260	.500	2392	.009

Table 1: Elemental ideation metrics for curation products in field study with Wilcoxon rank-sum statistics. Students in S2 had greater Fluency, Flexibility, and Novelty than students in S1. All results are statistically significant.

Students in S2 had greater Fluency, Flexibility, and Novelty than students in S1 (see Figures 4 – 6). All results are statistically significant (see Table 1).

Quantitative Experience Reports

After the final assignment, students were asked to answer ten Likert scale experience questions (see Table 2), and elaborate on responses. E1 and E2 were required. We derived E6–E10 from the Creativity Support Index, a survey metric for evaluating the creativity level supported by a tool [7].

Figure 7 represents 123 students' experience responses. Students agreed that curating information compositions helped them focus soft innovations, collect rich bookmarks, reflect

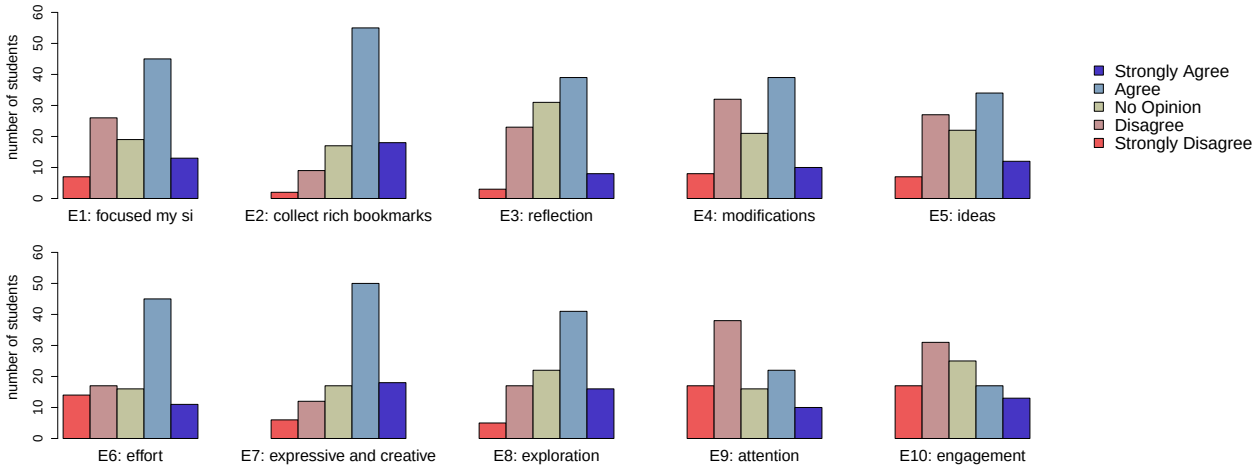

Figure 7: Results from students' experience responses for E1–E10. Blue bars represent agreement. Red bars represent disagreement. A majority of students agreed with every statement, except for E9 and E10.

Question	χ^2	$p <$
E1: Using InfoComposer to develop compositions focused my soft innovations.	14.0	.008
E2: InfoComposer helped me collect rich bookmarks.	12.0	.019
E3: The information composition authoring process made me reflect on my initial viewpoint.	21.1	.01
E4: Using InfoComposer to develop compositions inspired me to make changes, extensions, modifications, or enhancements to your original creation.	26.6	.001
E5: InfoComposer enabled me to develop ideas.	11.9	.019
E6: What I was able to produce was worth the effort I had to exert to produce it.	9.9	.043
E7: I was able to be very expressive and creative while doing the activity.	19.6	.001
E8: It was easy for me to explore many different ideas, options, designs, or outcomes.	15.2	.005
E9: My attention was fully tuned to the activity, and I forgot that I was using InfoComposer.	6.8	.15
E10: I was very engaged in this activity - I enjoyed this activity and would do it again.	3.6	.47

Table 2: Experience report statistics for second semester. χ^2 shows significant difference from uniform distribution.

upon initial viewpoints, inspire changes, explore variations, and develop ideas. Students felt expressive and creative. Agreements for E1–E8 were all statistically significant (see Table 2).

Qualitative Experience Reports

We analyzed qualitative experience reports data with coding methods derived from grounded theory, discovering themes: (1) emergent ideas; (2) reflection; (3) focusing; (4) exploring variation; and (5) deeper research.

Many students reported new ideas emerging in the process of curating rich bookmarks.

> U9: I think [the] organization one experiences using InfoComposer is good, but the development that results is great. It's building these compositions that allows for emergent creations.

Through reflection, students discovered new ideas, such as how to make their soft innovations stand out against competition. The holistic representation of an information composition supported thinking about connections among ideas, focusing answers, and revealing what was missing.

> U51: I had the ability to see my plan all laid out in front of me, in a manner that showed connections. Because it did this, I could see the holes in the innovations, which could be improved.

The rich bookmark visual and implicit structure of information composition supported exploring variations and conviviality. Reflection upon these variations transformed soft innovations.

> U43: In my head I saw it one way, but once playing around with ideas, new designs and ideas come to mind.

The process of collecting rich bookmarks required students to search to find relevant information. Deeper research emerged as a theme in students' responses. Students gained new understandings about soft innovations while curating rich bookmarks. They expanded on new understandings, forming new searches and exploring prior searches more deeply.

The metadata of rich bookmarks aided students' understanding of ideas, and stimulated the evolution of ideas.

> U77: I was making a barcode eye lens, so you can take a photo for and go to a certain link ... Then, I found in the metadata that the eye is a sensory organ, and there are others, such as skin. I wanted ... a photo for the skin. [I] found out that someone is printing barcode tattoos.

Not all students reported new ideas in their soft innovations. Despite our efforts to emphasize rich bookmarks, 15 (12%)

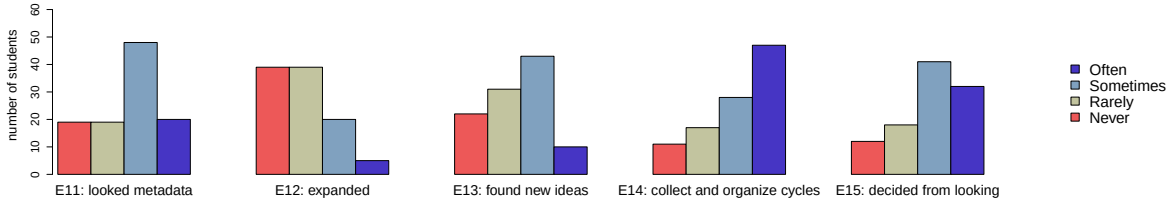

Figure 8: A majority of students reported looking at metadata and finding new ideas. Students frequently engaged in cycles of collecting and organizing, making decisions about what to collect from existing rich bookmarks.

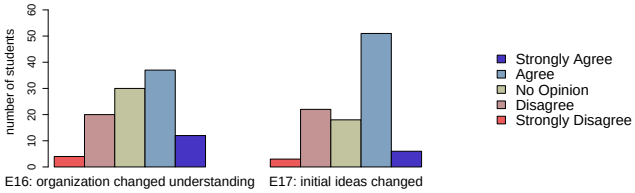

Figure 9: A majority of students agreed that their interpretations changed through organizing rich bookmarks.

Question	χ^2	$p <$
E11: I looked at metadata for a rich bookmark.	23.3	.001
E12: I expanded metadata.	31.6	.001
E13: I found new, unexpected ideas [in metadata].	22.1	.001
E14: I switched back and forth between collecting rich bookmarks and organizing them in my information composition.	29.2	.001
E15: I made decisions on what rich bookmarks to collect based upon what I saw in my information composition.	20.2	.001
E16: Organizing rich bookmarks changed how I understood the ideas I collected.	34.3	.001
E17: My initial understanding of the ideas represented by one or more rich bookmarks changed in the process of collecting and organizing other rich bookmarks in my information composition.	72.7	.001

Table 3: Experience report statistics for S3. χ^2 shows significant difference from uniform distribution.

still did not understand what a rich bookmark is or how to create one in InfoComposer. They equated InfoComposer to other graphic design tools, missing out on semantic aspects of rich bookmarks and information composition.

More Focused Experience Reports: Third Semester (S3)

We iterated on experience report questions in a third semester, focusing on reflection and interpretation through rich bookmark interaction. Software remained the same as the second semester. A new set of students participated. Table 3 shows new questions and response statistics.

Responses for E11–E15 were never, rarely, sometimes, and often. Responses for E16–17 were the same as E1–E10. See Figures 8 and 9 for results. Responses for E11–E17 were all statistically significant (see Table 3).

A majority of students examined metadata. Of these, most expanded metadata, reflecting on deeper details. New ideas emerged for students as they looked at metadata.

DISCUSSION

Curating rich bookmarks as information composition promoted *reflection-in-curation*. The Fluency metric and experience reports (E2) show that students were able to effectively collect rich bookmarks. Each new rich bookmark collected needs to be organized, in the emerging context of the composition. Students engaged the composition of rich bookmarks as *external* cognition [25], performing cycles of collecting and organizing (E14), feeding *internal* cycles of reflection and interpretation (see Figure 2). New interpretations and ideas emerged in organizing collected information (E3, E4, E16, U9, U14). Initial interpretations of rich bookmarks changed (E17), during curation, through reflection.

Visual and semantic components of rich bookmarks promoted reflection and interpretation. Students reflected upon collected ideas, looking over the space of rich bookmark visuals, and making decisions about what to collect (E15). Students were able to visualize their ideas externally and explore variations through the manipulation of visual components (E8, U43). The semantic component of rich bookmarks helped students understand, explore, and reflect upon represented ideas (E13, U77). Students in S3 examined metadata, expanded nested structures, and generated new ideas in the process. Students were not required to look at metadata to curate an information composition, yet a majority still did (E11), discovering new ideas in the process (E13).

Ideation metrics show that with the progression of software and pedagogy from S1 to S2, students were more creative, curating more novel and varied ideas. Students reflected upon decisions to collect rich bookmarks from a greater variety of information sources. This shows that students engaged in more varied interpretations for the diverse rich bookmarks they collected. In tandem with results about evolving interpretations and emergence, increased creativity and engagement in reflection were connected.

We helped students in S2 understand and curate rich bookmarks by incorporating Rich Bookmark Variety as a grading metric for the introductory assignment and adding a visual indicator for unlinked clippings. Eighty-five percent of students authored compositions with more than 75% rich bookmarks.

Students disagreed that their attention was fully focused and that they enjoyed the activity (E9, E10). This is not surprising. The assignment was part of the final exam, not something students typically enjoy. These CSI metrics are particularly applicable when participants see themselves as artists or designers [7], but cannot be generalized to all contexts.

Students reporting negative experiences, mostly cited misunderstandings or problems with InfoComposer. We continue to iterate on documentation and functionality.

IMPLICATIONS FOR DESIGN

Findings yield implications for design of pedagogy and tools: (1) educators should engage students in reflection-in-curation; (2) designers should integrate visual and semantic representations to promote reflection and interpretation; (3) designers should create convivial tools for education; and (4) educators and designers should engage in iterative co-design to support learning experiences. More broadly, researchers should expand situated context to include internal processes.

Engage Students in Reflection-in-Curation

Educators should engage students in reflection-in-curation through pedagogy and tools. Iterative cycles of collecting and organizing information help students reflect on ideas and form new interpretations. Pedagogy should introduce students to curatorial processes through lectures, readings, and assignments. Educators should employ tools that support combinations of searching, collecting, and organizing.

Integrate Visual and Semantic Representations

Representations that integrate visual and semantic components promote reflection and interpretation. Interpretation of a rich bookmark is rooted in perception of the visual. Visual clippings are flexible, conducive to multiple interpretations. Students reported looking over their existing collections of rich bookmarks in making decisions about what to collect.

Metadata supports interpreting ideas represented by a rich bookmark and exploring related information through expansion of nested entities. Metadata exposes constituent details and relationships. New ideas emerge, as connections are formed through reflection upon how information in metadata relates to ideas presented visually by other rich bookmarks.

Semantic components need to be represented fluidly, presented when needed and connected with the visual, such as with in-context metadata details-on-demand. When organizing rich bookmarks as information composition, persistently showing all detailed metadata would bury the user in details and increase the load on working memory [1], interfering with discovery of emergent juxtapositions.

Create Convivial Tools for Education

Designers should create convivial tools for education. Convivial tools enable learning through creative action rather than "purposeful and programmed training" [15]. No two people have the same experience when using a convivial tool, nor do they create the same product. Students report that InfoComposer helps them express and explore ideas, deriving new knowledge through personal interpretation.

Perform Iterative Co-Design of Pedagogy and Tools

Educators and designers should engage in iterative co-design of pedagogy and software tools. Field studies across semesters enable educators and designers to evaluate impact of pedagogy and software. We introduced InfoComposer in DPCE pedagogy to help students create soft innovations. Students in the first semester misunderstood how to collect surrogates, which led us to the concept of rich bookmarks, which in turn required new visual affordances and interactions in software, and improved explanation and explicit grading metrics in pedagogy. As a result, students curated more novel and varied ideas for prior work collection in S2.

Employing creativity metrics as for grading assignments can help students understand how to effectively use novel creativity support tools and incentivize creativity. Students in S2 curated novel and varied ideas for the final, yet were only given these grading metrics in the introductory assignment.

Expand Situated Context for Reflection

Situated context is a key idea in HCI [29]. Prior notions of situated context emphasized understanding and supporting tasks that people perform, or, more broadly, activities they engage [4]. The present research on reflection identifies these as *external* situated context processes. Tools that support reflection and interpretation need to also address *internal* processes of situated contexts, i.e., thinking, meditation, improvisation, connecting, and construction. By involving internal components of situated contexts, HCI will progress from task-centered, to activity-centered, to *process-centered design*.

CONCLUSION

We supported reflection-in-curation among students using InfoComposer for developing soft innovations. Rich bookmarks provoked students to reflect upon and interpret visual and semantic representations. Through iterative co-design of pedagogy and software, we helped students engage in cycles of collecting and organizing information, leading to more novel and varied ideas. Students made decisions about what to collect through reflections upon their information compositions. Students derived new interpretations while exploring metadata and organizing rich bookmarks.

The representational medium of *rich bookmarks*, which integrate detailed metadata semantics and visual clippings, provides essential support for reflection, interpretation, and creativity. The visual component represents multiple ideas, affording flexible and ambiguous interpretation to support creativity, learning, and problem solving. During curation, students reflect on the visual, stimulating decisions about what to collect and how to organize. The semantic component represents the explicit relationships of knowledge graphs, stimulating interpretation and exploration of related ideas. We designed rich bookmarks as visual semantic artifacts, representations for people to perceive and manipulate via external cognition to stimulate internal processes of reflection and interpretation, in ways that are, as Scaife and Rodgers prescribe, "appropriate for the learning environment" [25].

Rich bookmarks have a valuable role to play in education. Educators can curate rich bookmarks as information com-

position to develop curriculum and engage students in discussion. The visual is stimulating and flexible; the semantic enables drilling down into further investigation. Information composition supports connecting and combining. Rich bookmarks are malleable representations for externalizing ideas in unique ways that fit personal cognitive processes [22]. New representations and tools are needed: flexible, convivial, and deep. For education, integrate representations and tools with pedagogy and assignments to engage students. And iterate.

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