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Isolating and addressing theoretically-grounded limitations from the rapid translation of interaction design across media platforms

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Abstract: Designers must frequently work rapidly under deadlines to produce minimum viable products (MVPs) in collaboration with other disciplinary experts. While results may be good enough for now, it is important that limitations of hasty work are not codified as permanent design solutions. A method called function mapping has previously been shown to aid in the translation of theoretically-derived functions across media platforms, where functionally equivalent products may need to appear superficially dissimilar, thus complicating true equivalency. Here we demonstrate function mapping's efficacy at the threshold between MVPs and revisions. We recount a process of rapidly translating a virtual environment for a VR headset into an exhibition gallery with 90 feet of touchscreens. We then use function mapping to identify shortcomings and to strategize next steps.

Keywords: cross-media design, design methods, theory-driven design, virtual reality

1. Introduction

Design work often unfolds within the constraints of tight deadlines, making it difficult to engage in critical reflection and evaluation until after initial deployment. This reflection and evaluation is particularly challenging when the design is rooted in theory from other disciplines and is thus not top of mind to designers. To address these constraints, we turn to the work of Sekelsky et al. (2023), who recently introduced a method called function mapping. This method is designed to aid multidisciplinary teams in translating theoretically-derived cognitive and affective functions across media platforms.

Sekelsky et al.'s (2023) application of function mapping specifically demonstrated how theoretical assertions about learning could facilitate the translation of Scale Worlds, a virtual



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learning environment, across three distinct media platforms. Function mapping helped the authors ensure that the theoretically-derived functions embodied on one media platform were retained in the translation process to other platforms at the level of discrete design features. This translation was implemented over an extended period of time in a ground-up development process. Here we explore how function mapping may impact rapid development, and how it may compensate after the fact for impromptu decisions made in the moment. We propose that function mapping not only aids in translating features across multiple media platforms, but also serves as a reflective tool for development teams to identify overlooked aspects and gaps in functionality. Furthermore, it may serve as a strategic framework to assist teams in developing a plan for future implementations that addresses any deficiencies.

We explore this new application of function mapping via a case study of the rapid development of a fourth version of Scale Worlds (SW-Luminary) intended for the Keith and Catherine Stein Luminary at Boise State University. In contrast to Sekelsky et al.'s (2023) deliberate process, we anticipated that our conversion process for SW-Luminary would superficially mimic features at occasional expense to their intended and underlying functions — team member workloads compromised reflection-in-action on theoretical function. Ultimately, our oversight was particularly evident in what we consider a project-critical scale cognitive process known as numerical proportional reasoning (NPR; Magana et al., 2012). Notably, our translation for the Luminary overlooked NPR, despite it being facilitated in previous versions. This function holds significance as one of five components in a guiding theoretical framework (scale cognition; Magana et al., 2012; Tretter et al., 2006a,b). Our experience demonstrates function mapping's reach, emphasizing its role as a reflective tool and as a blueprint for future iteration and implementation across media platforms.

2. Function mapping for cross-domain translation in interdisciplinary media development

Function mapping was developed as an applied method to ensure that relevant theory is intentionally translated into cognitive and affective functions embodied in the design of media features. In turn, this supports development teams in the systematic translation of those functions from the original media platform to alternative platforms (Sekelsky et al., 2023). Effectively, theoretical assertions from a non-design domain (for us from the learning sciences literature) are expressed in design specifications, requiring expertise in both non-design and design disciplines. In this regard, function mapping facilitates interdisciplinary media development by ensuring that the concerns of each discipline are considered openly and by revealing interdisciplinary conflicts that must be resolved. For instance, we have found that addressing learning theory by engaging learners deeply can sometimes require a reduction in usability. Depicted in Table 1, this cross-domain translation is documented in a function map, which is a simple table that tracks theoretical assertions and design specifications in separate columns, at one feature per row. The interpretation of platform-dependent features may then be progressively added to the original function map.

Table 1 Representation of function mapping structure demonstrating the adaptation (A) or preservation (B) of features across platforms.

Theoretical Assertion	Design Specification	
	Platform 1	Platform 2
Theoretical Assertion A	Design Specification A1	Design Specification A2
Theoretical Assertion B	Design Specification B	

This methodological approach is particularly relevant for projects such as Scale Worlds, which is intended to help students conceptualize abstract concepts of size and scale. The Scale Worlds research team is composed of faculty and students representing science education, human factors, and user experience and user interface design (UX/UI). Throughout the development of Scale Worlds, this interdisciplinary team has had to negotiate specific design features based on conflicts between (a) usability and human factors precedents and best practices, and (b) learning theory specific to student comprehension of size and scale. Sekelsky et al. (2023) addressed the cross-platform development of Scale Worlds as features were migrated and re-evaluated based on the affordances of different technologies — from a room size Cave Automatic Virtual Environment (CAVE) to a virtual reality head-mounted display (HMD), and finally to a two-dimensional web-based platform (SW-CAVE, SW-HMD, and SW-Web, respectively). See Figure 1 for a comparison.

In this case, function mapping assisted the development team in ensuring that the theoretically-derived functions were retained in the translation process to discrete design features. This process of embodying theoretical functions across media — in consideration of platform affordances and disciplinary knowledge — requires time, consideration, and a multitude of revisions over the course of a project timeline, none of which were available in the initial two-week development of SW-Luminary, which we discuss.

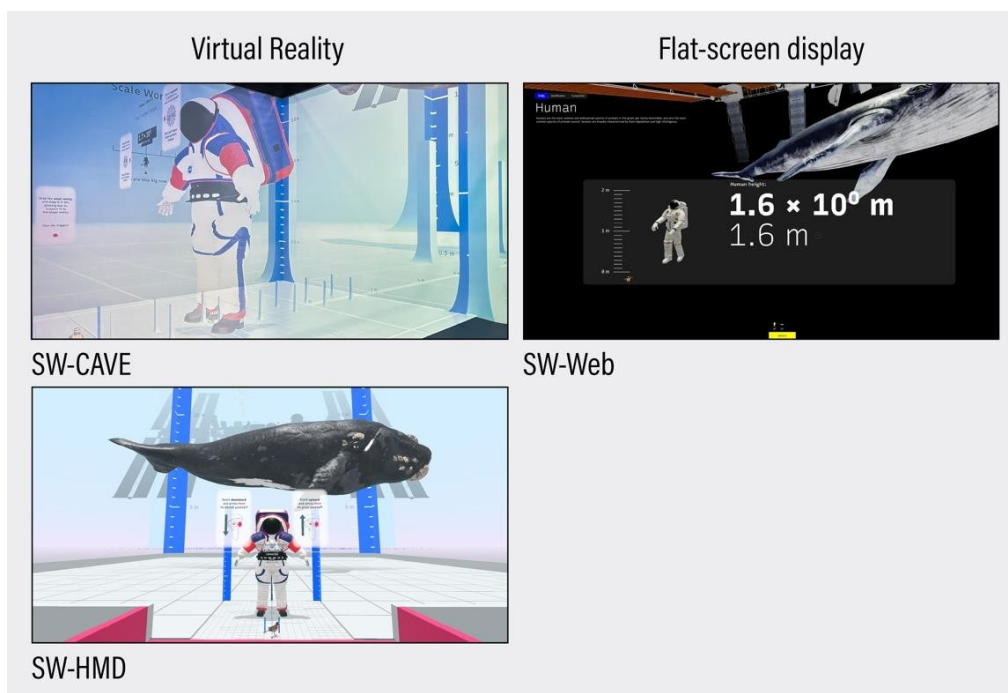


Figure 1 Three established versions of Scale Worlds: SW-CAVE, SW-HMD, and SW Web.

3. Addressing disciplinary challenges in the Luminary implementation

The Luminary is an “all-digital museum space with touch-activated glass walls, six 26K-lumen projectors, and 7.1 digital surround sound, producing a range of immersive, interactive and sensory experiences,” with three walls totaling 90 ft length and 8.75 ft height (27.4×2.7 m; The Stein Luminary, Boise State University, n.d.). In designing for this novel interface, we encountered a range of technical challenges that inhibited our ability to thoughtfully and intentionally apply function mapping at the onset. As a starting point, the team had to work from SW-HMD, as it was the most up-to-date version at the time. However, the immersive 3D nature of SW-HMD made it the least suitable version for translation to a screen-based interface. In contrast, SW-CAVE runs on a system where visuals are projected onto walls (like the Luminary), while SW-Web employs UI elements native to flat screens (which constitute the Luminary). Thus, relatively more had to be “reinvented” in the conversion of SW-HMD to SW-Luminary.

Complicating this process were specific disciplinary challenges faced by both the design and development leads. Because Scale Worlds is designed to help students conceptualize scientific size and scale, accurate sizing is critical for its efficacy — e.g., a meter ruler needs to be accurate to the meter. Consequently, in the development of SW-Luminary, the design lead had to allocate significant time to confirm precise measurements of the space, which were inconsistently reported in available documentation. With time spent assessing the scale of the display, he had limited opportunities to think deeply about the theoretical goals of Scale Worlds and how SW-Luminary might fulfill them. For instance, despite a preference for more

embodied and gestural interactions in the development of earlier versions, buttons were immediately implemented to proactively reduce technical challenges for the developer. Additionally, the extensive space available on 788 sq ft (74 m²) of wall suggested possibilities for visual and verbal communication with graphic overlays not practical in other versions of Scale Worlds, but there was too little time to maximize their potential.

Meanwhile, the development lead faced various technical barriers that continuously redefined which desired features were feasible. While the design lead's challenges largely revolved around translation and representation, both visually and theoretically, the development lead had to tackle software and hardware limitations. Specifically, due to the novelty of the interface, there were very few software packages or similar projects from which he could build. This required intermittent communication with Luminary staff and remote testing of iterative deployments, which presented a significant barrier to the development process.

4. Description of Scale Worlds and theoretical foundations

We now describe some of the theoretical basis that informed design decisions for Scale Worlds, and we introduce function mapping as the means for guiding such decision making. The Scale Worlds learning environment is intended to help students conceptualize scientific size and scale by immersing them in a series of experiences of scale beyond that which is accessible in everyday life. The environment features widely recognized entities representative of each power of ten (e.g., an astronaut for 100 m, a right whale for 101 m, and the International Space Station for 102 m). The user is able to grow and shrink by powers of ten to reach these scale-worlds, growing up to 10¹² and shrinking down to 10⁻¹². Numeric indicators throughout the environment reinforce size using both scientific and standard notation, and a "stacking" feature lines up ten of the previous entities with the current entity to reify ten-step jumps between worlds. Additionally, multimodal cues such as color and sound help bracket scale-worlds into conceptual groupings (e.g., after the user passes the visible wavelength of light, the scene turns to grayscale). See Figure 2 for examples of each feature.

Magana et al.'s (2012) scale cognition framework forms the theoretical basis of many Scale Worlds features. The framework delineates five fundamental cognitive processes that facilitate the comprehension of size and scale: (1) generalization and (2) discrimination, or categorizing and ordering entities based on their size; (3) logical proportional reasoning, or finding equivalencies between scale ratios (i.e., A is to B as C is to D); (4) numerical proportional reasoning, or numerically estimating ratio differences; and (5) mathematical reasoning, or assigning absolute numbers. In a synthesis, we proposed an additional subtype of logical proportional reasoning, nested logical proportional reasoning, which illustrates relationships between entities across scale-worlds with a central size as an anchor (i.e., A is to B as the shared B is to C; Delgado & Peterson, 2018). Furthermore, Scale Worlds embodies a scientific conceptualization of scale from Tretter et al. (2006a), who found that scientists engage in a process of "mentally jumping" between distinct scale-worlds (p. 1077).

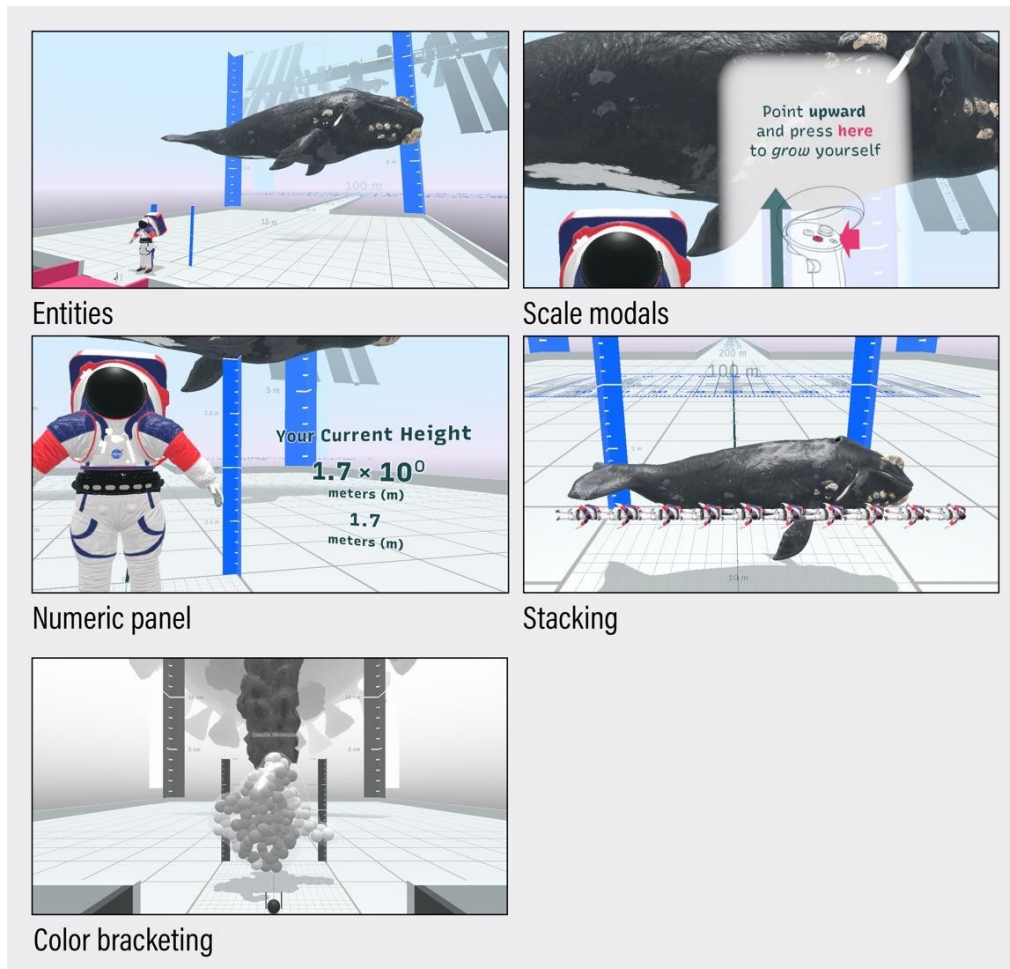


Figure 2 Discrete examples (from SW-HMD) of entities representative of powers of ten; scale modals; numeric panel; stacking; and grayscale color bracketing.

Function mapping was initially developed as an applied method to ensure that these scale cognition processes and principles from the literature were thoughtfully and intentionally translated into functions embodied in the design, which were subsequently translated to new platforms based on media affordances (Sekelsky et al., 2023). For example, the assertion that scientists “mentally jump” from one scale-world to another (Tretter et al., 2006a) is embodied in the virtual environment as a scaling animation intended to facilitate the feeling of growing or shrinking, maintaining the conceptualization of the user traveling to a new scale-world rather than the absolute size of the entities changing. Another example of assertion to specification translation is the ordering of the entities from small to large, which is intended to enable discrimination, or ordering entities based on their size (Magana et al., 2012). These are both instances of core features that were readily retained across all versions. In contrast, an example of different embodiments of features based on a single assertion from Sekelsky et al. (2023) are the design specifications for mathematical reasoning. In SW-CAVE, posts are mapped to the four corners of the physical CAVE walls with unit measures, and they update as the user scales up and down. In the translation to SW-HMD, we forwent the posts because we were no longer mapping to a physical space, and instead

designed standing rulers that bracket each entity in the virtual environment, still allowing users to assign an absolute number. Finally, in SW-Web, a numeric ruler is overlaid as a UI element on a bisecting plane, facilitating measurement and bringing attention to the entity in the current scale-world the user is viewing. See Figure 3 for a side-by-side comparison. While these features are visually dissimilar, conceptually they all facilitate the same scale cognitive process.

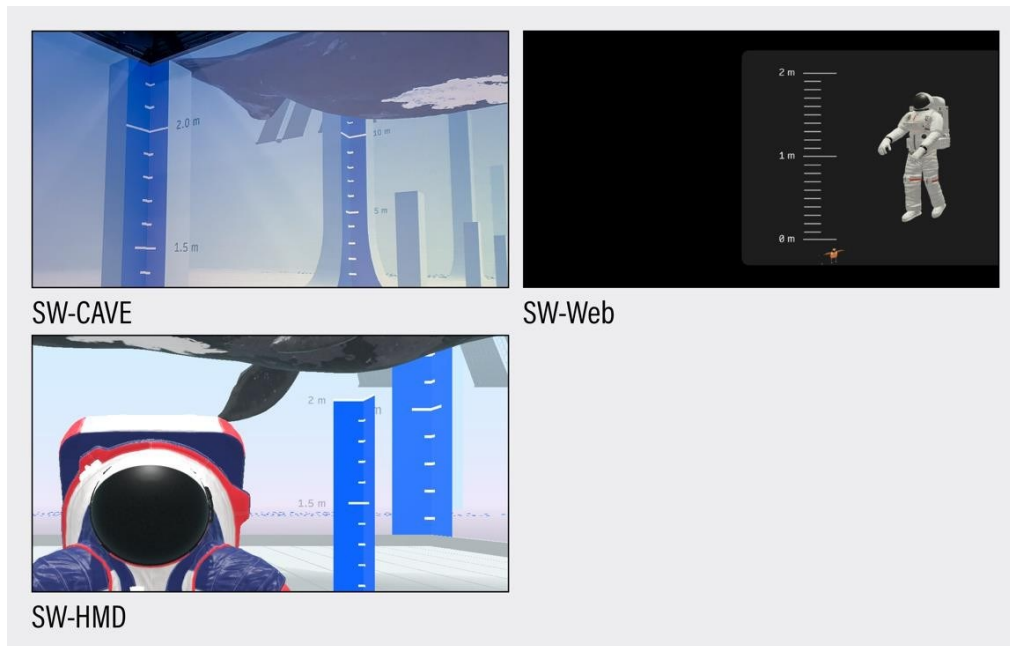


Figure 3 Comparison of SW-CAVE posts, SW-HMD rulers, and SW-Web bisecting plane.

4. Function mapping and results of rapid development

The accounting of these instances of function mapping is but a brief demonstration of how this process utilizes relevant theory to inform discrete design decisions and cross-platform translations that in turn increase the likelihood of positive learning outcomes. While it was not feasible to apply function mapping in the rapid development of SW-Luminary, we knew that there would be opportunities to refine it, if only in subsequent adaptation for similar large-screen installations. Thus, we engaged in the deliberate approach of function mapping to assess SW-Luminary outcomes and anticipate future revisions. Table 2 adapts Sekelsky et al.'s (2023) function map of SW-CAVE, SW-HMD, and SW-Web, with the added consideration of SW-Luminary, depicted in Figure 4.

Table 2 Following page: Function mapping from established versions of Scale Worlds to SW-Luminary on distinct media platforms (adapted from Authors, 2023, p. 5). Sources: (1) Tretter et al., 2006a; (2) Weller et al., 2013; (3) Wilson, 2002; (4) Lakoff & Johnson, 1980; (5) Tretter et al., 2006b; (6) Magana et al., 2012; (7) Author and Author, 2018.

Theoretical Assertion	Design Specification	
	Established Scale Worlds Versions	SW-Luminary
A. “Experts used strategies of mentally jumping to a new scale-world” (1 [p. 1061])	Scaling animation	<i>Preserved</i>
B. Abstract linkages between worlds and: mathematics (1); numeracy (2); embodiment (3); orientational conceptual metaphor (4); and mental models	Interactive navigation panel (SW-CAVE); passive numeric panel (SW-HMD); numbers in bisecting plane	Passive numeric panel
	Up-down gesture on exponent (SW-CAVE); up-down gesture with button (SW-HMD); zooming concept conveyed verbally (SW-Web)	Touch to scale, hitboxes paired to entities
C. Link to human scale (1 [p. 1079])	Initial scale-world is Human World	<i>Preserved</i>
D. Size landmarks as “exemplars of a category” (5 [p. 307])	Entity presence and varying sizes	<i>Preserved</i>
E. Size landmark memory traces (1) and numeracy (2) for base-10 number system	Limited number of entities keyed pairwise to decimal places	<i>Preserved</i>
F. Generalization (6)	Visual experiential cues	<i>Preserved</i>
	Number line grouping of entity icons by metric unit (SW-Web only)	N/A
G. Discrimination (6)	Entities ordered small to large	<i>Preserved</i>
H. Logical proportional reasoning (6) and nested LPR (7)	Fixed entity positions before and after scaling	<i>Preserved</i>
	Ratio panel consistency (SW-Web only)	N/A
I. Numerical proportional reasoning (6)	Forest of orientative posts keyed to CAVE dimensions (SW-CAVE), teleportation (SW-HMD), comparison mode (SW-Web); stacking (all versions); Numeric ratios in ratio mode (SW-Web only)	None

J. Mathematical reasoning (6)	Rulers on posts (SW-CAVE); standing rulers (SW-HMD); rulers on bisecting plane (SW-Web)	Vertical ruler on screen
	Metric grids	Vertical grid bisecting entities

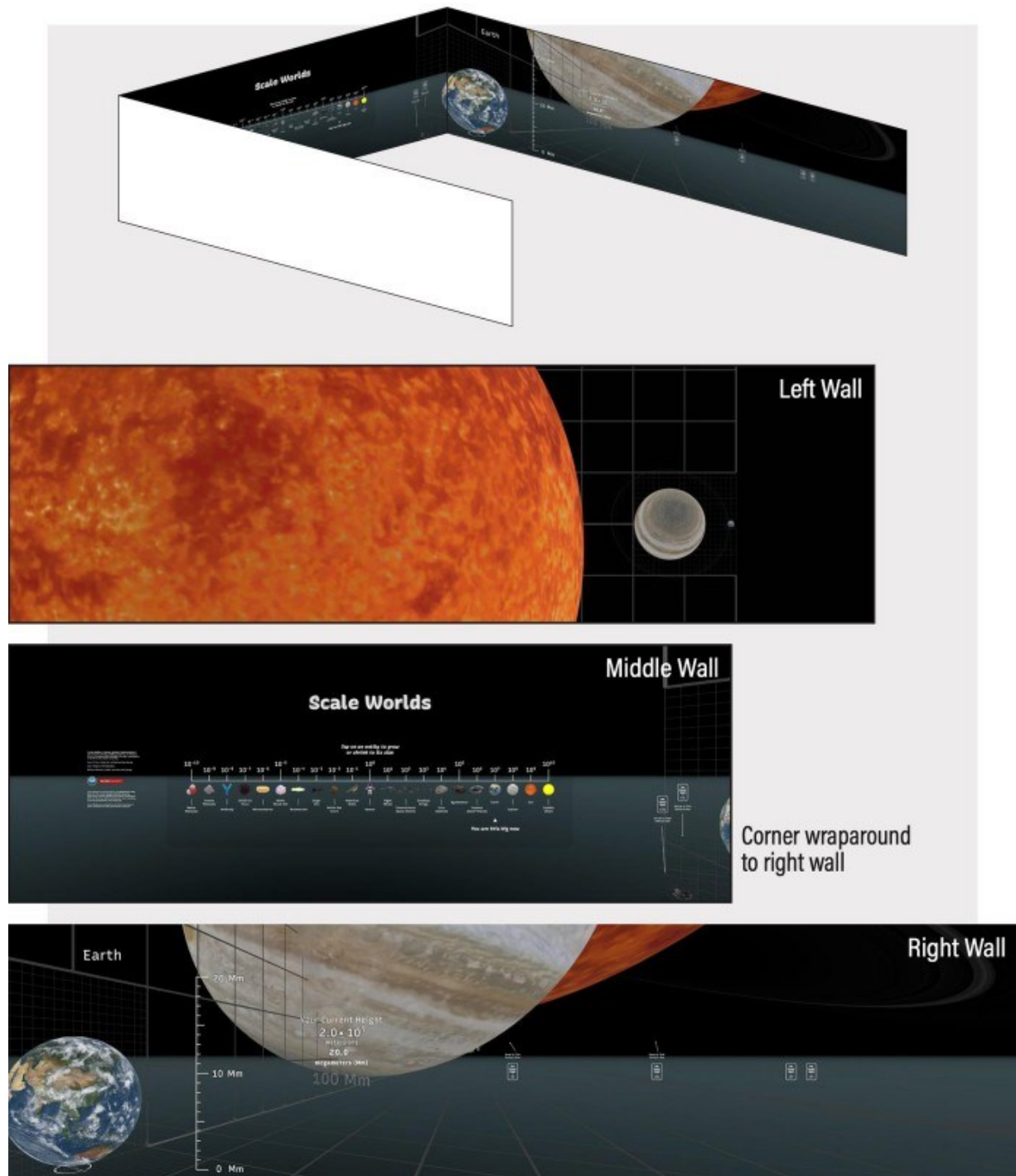


Figure 4 SW-Luminary.

As seen in Table 2’s function map, some features of Scale Worlds are uniform across platforms, including the Luminary (especially foundational Theoretical Assertions A, C, D, and E). These are core features of Scale Worlds that are platform-independent, such as the specification that each power of ten is represented by exactly one scientific entity (e.g., mitochondrion, acorn, Sun). Therefore, we describe only Theoretical Assertions B, I, and J in Table 2 in detail, as these mappings reveal differences between the hastily conceived SW-Luminary and the earlier versions of Scale Worlds.

Tretter et al. (2006a) concluded that scientists rely on mathematics to establish “abstract linkages” between scale-worlds (Table 2, Theoretical Assertions B). This suggested that we associate numeric representations of powers of ten with each scale-world and the entity within it. In SW-CAVE, the user directly manipulates an interactive navigation panel to initiate scaling, displaying their “current size” in scientific and standard notation. Conversely, SW-HMD features a passive numeric panel (as a heads-up display) for users to observe, while in SW-Web a bisecting plane overlays scientific and standard notation. SW-Luminary utilizes a numeric panel that is passive like SW-HMD’s version but is more prominent like SW-CAVE’s version (Figure 5).

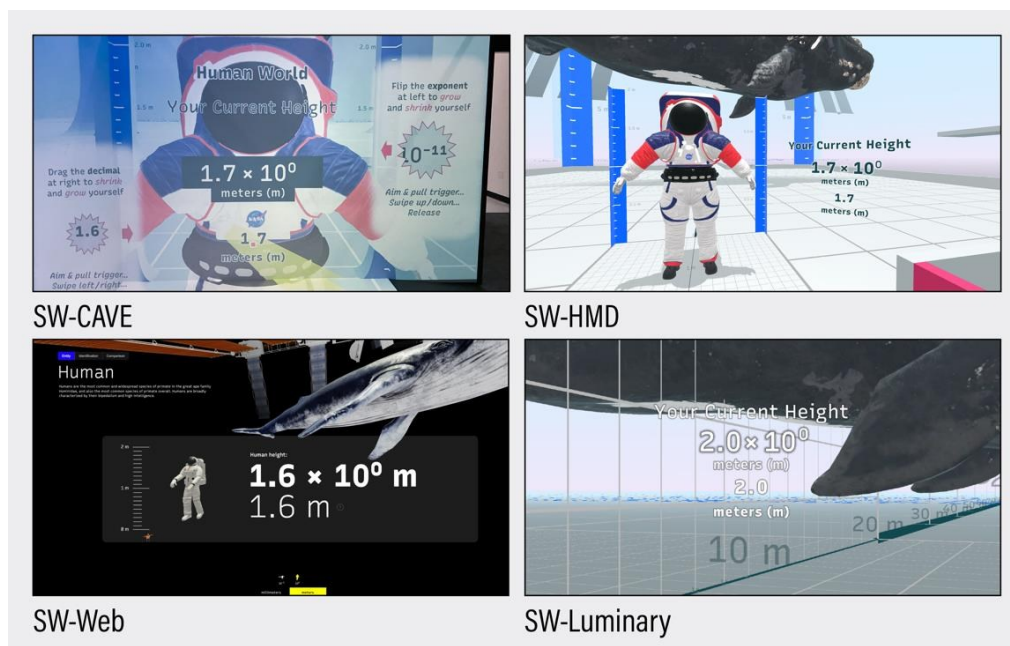


Figure 5 Comparison of SW-CAVE navigation panel, SW-HMD numeric panel, SW-Web bisecting plane, and SW-Luminary numeric panel.

Interaction with the navigation panel in SW-CAVE requires the user to point, click, and then make a gesture upwards or downwards to move the exponent (employing embodied cognition; Wilson, 2002), or a gesture right or left to move the decimal point. Doing so initiates the scaling animation. In SW-HMD, the user raises or lowers their arm while simultaneously pressing a button, cognitively binding the button press with an embodied directional gesture. SW-Web foregoes these gestures in line with more limited interactions common to websites, instead employing a mental model of zooming in or out as if through a viewport,

making SW-Web the least embodied of the three established versions. This is a concession to the allocentric user perspective of a relatively small 2D screen display, in which the environment is perceived as independent from the self. In contrast, users experience the virtual environments of the CAVE and HMD from an egocentric perspective, based on their personal position and point of view. The Luminary offers a hybrid allocentric–egocentric perspective, where visuals are clearly confined to surfaces, but can be large enough to relate to the user’s visible body. The scaling interactions in SW-Luminary take the form of an interactive number line and specific hitboxes that explicitly correspond to entities smaller or larger than the user (Figure 6), with a prompt to “shrink [or grow] to this entity’s size.” Thus, the interaction of tapping a button is not itself embodied, but the user’s natural incorporation into the space is, to some degree.

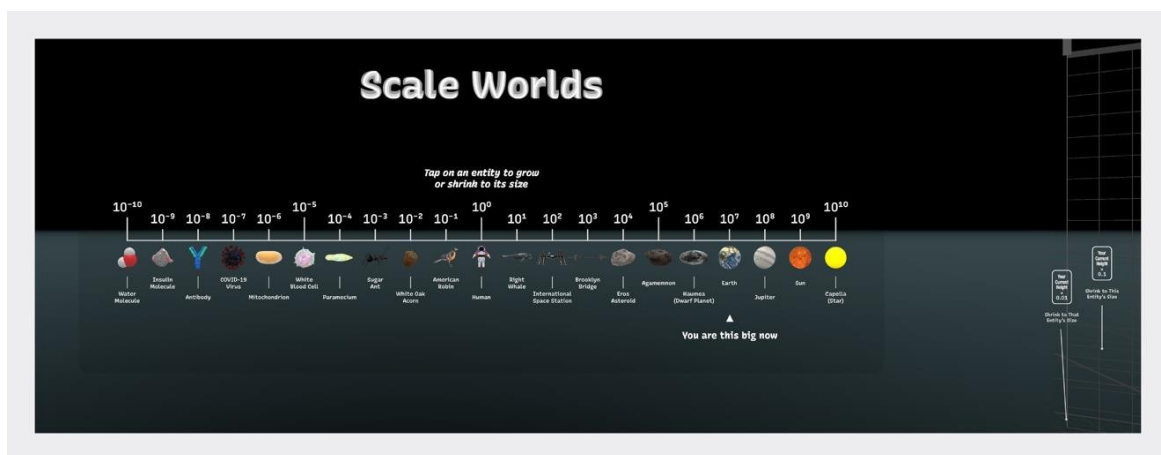


Figure 6 Interactive number line (left) and hitboxes (right) to scale up/down in SW-Luminary.

Magana et al. (2012) define mathematical reasoning (Table 2, Theoretical Assertion J) as the ability to assign absolute numeric values. As previously discussed, in SW-CAVE the four orientative posts at the corners of the physical CAVE include metric posts that facilitate mathematical reasoning. While we removed the orientative posts in SW-HMD, we retained two of their embedded rulers as the only portions that remained functional (given the user’s ability to teleport). In SW-Web, the bisecting plane contains a vertical ruler that measures the size of the currently selected entity. SW-Luminary utilizes a vertical ruler similar to SW-Web’s, mapped cleanly onto the screen and with the added benefit of being physically accurate in real space in Human World, where a meter is a meter.

Furthermore, all versions of Scale Worlds make use of a metric grid to further facilitate mathematical reasoning. For SW-HMD, we temporarily considered a second vertical grid that bisects all entities according to their arrangement scheme, but this was perceived as disturbing given the realism of the environment — it was as if a living human and bird were being impaled by the grid. This vertical grid was revisited for SW-Luminary, where its display on walls is an expression of diagrammatic language as opposed to a natural scene, with no apparent goriness accompanying bisection.

Magana et al. (2012) define numerical proportional reasoning (NPR; Table 2, Theoretical Assertion I) as the ability to numerically estimate ratio differences (e.g., B is ten times larger than A). For NPR, SW-CAVE utilizes a pattern of orientative posts to assist users in estimating the size of distant entities. This was deemed necessary because the absence of a ceiling display requires massive entities (10 and 100 times the user's apparent size) to be displayed at a distance, lest they be mostly obscured by the ceiling. The orientative posts are placed at the corners of the physical CAVE and repeat in the distance at the same increment, which makes it easier to gauge the size of a massive distant entity in relation to the user's physical size in the CAVE. In contrast, SW-HMD immerses the user fully and enables them to view and navigate the entire virtual environment. Teleportation serves the same function as the orientative posts, allowing the user to approach distant entities and engage in relative size comparisons. However, in the translation to SW-Web, neither the orientative posts nor teleportation could be replicated meaningfully. Instead, a comparison mode layers entities onto one another, facilitating a more accurate comparison of exponential size differences between them. Additionally, entities are labeled based on their relationship to the currently selected entity, such as "10x" and "100x." Upon reflection, SW-Luminary does not appear to offer a strong form of NPR, an oversight of its rapid development. While two entities at a time appear close enough to the user (as displayed on the wall) to permit reasonable comparisons with the self, other entities do not, being represented in normal pictorial fashion.

Theoretical Assertions B and J in Table 2 exemplify adjustments for SW-Luminary that appear to roughly maintain consistency with earlier versions of Scale Worlds, while Theoretical Assertion I appears to have been overlooked. Thus, unlike the more deliberate process of SW-Web's development, the rapid development of SW-Luminary came at a functional cost. Technical and time constraints certainly contributed to this oversight. However, we were surprised that only one theoretical assertion tracked in the function map was overlooked. We suspect that this conformance is an indirect result of previous experience with function mapping and familiarity with Scale Worlds. The Stein Luminary is similar to the CAVE in its room size scale (although it is a much larger room than the CAVE) and in the user's ability to see their own body and compare it to virtual elements, and to web display in its reliance on screens.

A revision of SW-Luminary, or further conversion for a similar installation — these types of display are increasingly common in universities and museums — would benefit from turning the retrospective function mapping into formative specifications. Previous versions of Scale Worlds suggest obvious solutions for facilitating NPR, thus addressing SW-Luminary's primary deficiency. Within the visualized environment, a stacking action that has been programmed into SW-CAVE and SW-HMD (Table 2) could be incorporated, with copies of the entity currently about one-tenth the size of the user automatically stacking next to the entity upon arrival in each scale-world. Furthermore, graphic overlays could be created to replicate the numeric ratios in ratio mode found in SW-Web, with entities in ratios such as 0.001 : 1 : 1,000 in a corresponding diagram (Sekelsky et al., 2023, p. 9). This dual solution for NPR would utilize both the egocentric quality of a large-scale installation like the Stein Luminary

and the allocentric quality of its digital screens, for which the graphic designer's regular techniques are all applicable.

5. Conclusion

Uninformed design adaptation across media platforms may suffer from superficial similarity that masks a reduction in functionality, as cognitive and affective functions are lost in minimal feature translation. In development of SW-Luminary, we ultimately embodied most of the theoretical assertions from the other versions of Scale Worlds without employing function mapping. In this case, we suspect the established precedents of SW-CAVE and SW-Web offered features that had been carefully specified, and platform similarities (or goodness of fit) may have meant that our relatively careless transferal process in fact tended to bring underlying functions along with their feature expressions.

For this reason, function mapping serves as a method for deriving design features from theoretical assertions outside of the design domain, especially in multidisciplinary development teams. The story of SW-Luminary's rapid development, and the retrospective analysis of the results of that effort, together give function mapping a place at the threshold between minimum viable products (MVPs) and subsequent revisions. We have demonstrated the benefit of function mapping when considering future revisions based on established theoretically-derived functions (in the case of restoring NPR to SW-Luminary in future work), and that the transfer of features across platforms may be reasonably effective when earlier implementations were principled (given that the SW-Luminary MVP did appear to broadly facilitate scale cognition). Underlying these uses, function mapping highlights the importance of intentionality in the design of theoretically-concerned media development and can be used to ensure that hasty results that were "good enough for now" are not codified as permanent design solutions, sending multidisciplinary teams, including designers, back to the literature.

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