Innovations in Science Map,
Assessment & Report Technologies

I-SMART

Developing and Evaluating Learning Map Models in Science: Evidence from the I-SMART Project

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Overview

The Innovations in Science Map, Assessment, and Reporting Technologies (I-SMART) project is a collaboration with five states (MD, MO, NJ, NY, OK), the University of Kansas Center for Accessible Teaching, Learning, and Assessment Systems (ATLAS), CAST, and BYC Consulting undertaken to produce materials that support comprehensive science assessments that include multiple measures of student progress over time. The project delivers innovative assessments in science and score reports that improve the utility of information about student performance. This report describes the project activities undertaken to meet Goal 1: Develop and evaluate a learning map model for science. The first part of the report details the steps used to develop an integrated and accessible science learning map model neighborhoods, in which science maps are connected to existing ELA, math, and foundational maps and other neighborhood maps, as supported by the research on student learning and universal design. The second half of the report describes how we conducted an expert review of the learning map model neighborhoods and how the results of that review led to a refined map model that includes nodes, connections, and multiple pathways that meet standards for content and accessibility and is ready to serve as the basis for assessments. The contents of the report provide sources of validity evidence for the I-SMART project.

Introduction

Learning map models are a type of cognitive model that represent the knowledge, skills, and understandings (KSUs) within a domain. Unlike learning progressions, learning map models have many inter-connected learning targets and represent multiple developmental pathways that students may follow as they learn. Learning map models have two basic elements, nodes and connections. Nodes are learning targets that represent important KSUs that students acquire as they learn. Connections from origin nodes to destination nodes show the order that KSUs are acquired. A learning map model provides a formal structure which can be used to guide instruction and assessment. A map can guide students, parents, and educators in determining where a learner has been, where the learner is now, and where the learner is going.

Within the I-SMART and DLM learning map models, the nodes and connections are constructed using specific design guidelines that address how content is represented (DLM Consortium, 2016). The nodes have a small grain size, are distinct from surrounding nodes, represent a single concept, and reflect principles of Universal Design for Learning (UDL; CAST, 2018) to accommodate variability among learners. The I-SMART and DLM learning map model nodes have been created to be free of barriers for students with sensory, mobility, or communication disabilities. Connections between the nodes describe the incremental development of knowledge or skill by connecting a less complex node to a more complex node. The connections also represent multiple appropriate learning sequences for students with the most significant cognitive disabilities and logical learning sequences for students with sensory impairments, limited mobility, or limited communication abilities.

The map development work that was was undertaken to meet Goal 1 of the I-SMART project expanded on the work of the Dynamic Learning Maps (DLM) science assessment system. The

DLM project began in 2010 with a U.S. Department of Education's Office of Special Education Programs award of a General Supervision Enhancement Grant to a consortium of states and the University of Kansas. The DLM project initially included the development of large-scale, learning map models in English language arts (ELA) and mathematics, the development of alternate content standards called Essential Elements (EEs), and an online alternate assessment system based on the EEs for students with significant cognitive disabilities (SWSCDs). A group of DLM consortium states self-funded additional assessment development in science in 2015. The resulting state-funded work in DLM resulted in an alternate assessment system in science for SWSCDs. In DLM science, the EEs (DLM Science Consortium, 2015) are the alternate content standards that describe rigorous academic expectations for SWSCDs and are linked to the Next Generation Science Standards (NGSS; NGSS Lead States, 2013a). The DLM science assessment system assesses 34 EEs.

The science EEs have the same structure as the NGSS, consisting of three dimensions called Disciplinary Core Ideas (DCI), Science and Engineering Practices (SEP), and crosscutting concepts (NRC, 2012). Each of the three science domains -- Earth and space science, life science, and physical science – has its own set of three or four DCIs that are core idea for K-12 science instruction. Each DCI (e.g., matter and its interactions) has two to five component ideas or topics (e.g., structure and properties of matter; NRC, 2012). Eight SEPs are the major practices that scientists use to build scientific knowledge and that engineers use to design and build system (e.g., planning and carrying out investigations). Seven crosscutting concepts unify the three science domains and have explanatory value (e.g., patterns). Like the NGSS performance expectations, each EE integrates one DCI, one SEP, and one crosscutting concept. We selected eleven of the EEs in three disciplinary core ideas (DCIs; i.e., physical science, life science, Earth and space science) as the learning targets for the I-SMART project. Essential Elements were selected to include all three science domains (Earth and space science, life science, and physical science), three grade spans within each domain (elementary, middle school, high school), and one unifying DCI within each domain. Preliminary learning map models of these 11 EEs were developed by DLM science before the I-SMART project's inception. The DLM maps developed initially had a narrower focus, more aligned to the performance expectations for the EE. The I-SMART project extended the DLM maps to include representation of foundational, pre-academic nodes and connections that precede science learning. Additionally, I-SMART maps included connections to existing DLM maps in ELA and mathematics.

The scope of Goal 1 for the I-SMART project was to develop further and evaluate the learning map model neighborhoods that represent the 11 science EEs. The research question associated with Goal 1 is: What nodes and connections best describe the pathways of cognitive development that students follow as they progress from birth to 12th grade in the DCIs and science or engineering practices (SEPs)? To answer this research question, Goal 1 contained two main objectives: (1) expand the current DLM science learning map model neighborhoods, and 2) conduct an expert review of the preliminary learning map models. The processes described in this report provide validity evidence for the I-SMART maps.

Map Development

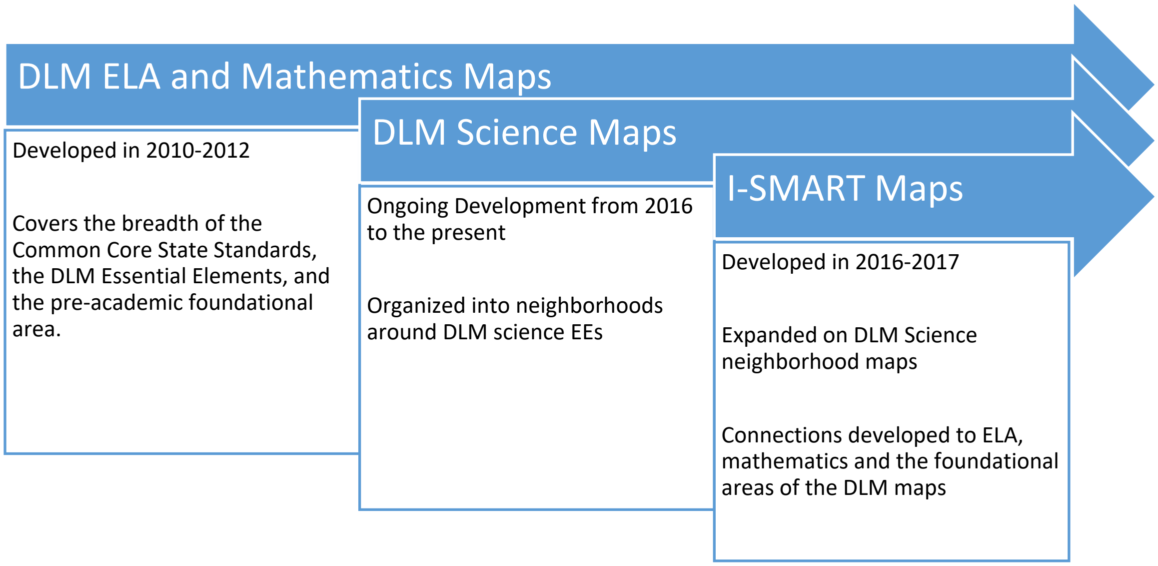
This section provides an overview of science learning map model development, which occurred for the I-SMART project as an extension of work undertaken for the DLM science alternate assessment.

Science Map Development Overview

We based the process used to create the I-SMART science learning map model on prior work on the development of the ELA and mathematics DLM learning map models. To develop the DLM learning map models that represent student learning in ELA and mathematics, the map development teams followed a four-step process (DLM Consortium, 2016). The first step involved the identification and representation of the relevant grade-level academic-content standards in the learning map models. The second step in the DLM map development process focused on the identification and representation of the supporting pre-academic (foundational) and grade-level knowledge, skills and understandings (KSUs) that support the development of the identified ELA and mathematics Essential Elements (EEs). To identify these KSUs, the map development teams performed an extensive literature review of the available cognitive and developmental empirical research, common instructional practices, and other relevant curricular information. Third, teams arranged and linked the content standard with the supporting foundational and grade-level KSU nodes. The fourth step was to create alternate pathways, where needed, around potentially problematic sections of the learning map models for students with specific disabilities (e.g., vision, hearing, and mobility).

We developed the DLM and I-SMART science learning map models in neighborhoods that focus on single EEs. The development process had several steps. First, we defined the breadth and depth of content for the neighborhood. To do this, we analyzed the content of each EE and used Next Generation Science Standards (NGSS) resources to create descriptions for the disciplinary core idea (DCI) and science and engineering practice (SEP) components. We did not include the crosscutting concepts because the DLM science alternate assessment does not explicitly target them (DLM Consortium, 2017). After identifying the content components, we conducted an extensive literature review on how students develop knowledge of these components. Based on the synthesis of this literature, the researchers created a set of nodes and connections that represent knowledge acquisition pathways. We used a fine-grain size to allow modeling of cognitive growth for students with significant cognitive disabilities and included multiple pathways that students could follow toward learning targets. Neighborhood pathways begin with pre-academic knowledge and end just beyond the EE. Nodes represent KSUs for the DCI and SEP components of the EE. Less complex nodes are connected to more complex nodes to describe the acquisition order indicated by the literature synthesis. The resulting hypothetical learning map model describes multiple, interconnected pathways of skills with increasing complexity that progress from pre-academic to grade-level knowledge of the DCI and SEP components associated with the EE.

The science map developers consulted with project staff who developed the DLM ELA and mathematics learning map models to refine the map-making conventions and decision-making processes according to the lessons learned in their development. Prior to developing the science learning map, the DLM technical advisory committee reviewed a proposed process. Figure 1 shows the development sequence of learning map models, culminating in the final maps used for assessment and reporting dashboard development for I-SMART Goals 2 and 3.



DLM ELA and Mathematics Maps

Developed in 2010-2012

Covers the breadth of the Common Core State Standards, the DLM Essential Elements, and the pre-academic foundational area.

DLM Science Maps

Ongoing Development from 2016 to the present

Organized into neighborhoods around DLM science EEs

I-SMART Maps

Developed in 2016-2017

Expanded on DLM Science neighborhood maps

Connections developed to ELA, mathematics and the foundational areas of the DLM maps

Figure 1. Development of Learning Map Models over Time

Resources and Literature Used in Science Map Construction

Science map development for both DLM science and the I-SMART project focused on the development of *neighborhoods* surrounding the topics contained in the EEs. Resources used in science map development included (1) learning progressions literature, (2) alternative conceptions literature, (3) *NGSS* appendices, (4) AAAS science literacy maps, and (5) cognitive psychology literature. A brief description of how we used each resource type follows.

The learning progressions literature provided descriptions of DCI development for many *Framework* (NRC, 2012) topics and some of the SEPs. This literature was used to develop nodes in the science learning map model that describe pathways toward conceptual understanding and skill development. The learning progressions literature also provided examples of how to observe the knowledge, skills, and abilities described by the nodes. Important considerations for science learning map models that are typically not considered in models of the ELA and mathematics content include changes in the nature of student thinking as understanding develops (Alonzo, 2018). As understanding develops, students' early versions of science ideas, or alternative conceptions, can be very different from accepted scientific concepts, but some of these alternative conceptions are productive cognitive stepping stones (Duncan & Rivet, 2013). Stepping stones are states of student knowledge that are significantly different than the prior state and represent a conceptual reorganization in students' thinking (Wiser, Frazier, & Fox, 2013). Although stepping stones represent student understandings that often include misconceptions or non-canonical ideas, nodes in the science learning map describe these states only regarding their scientifically accurate components.

The *NGSS Appendices* (NGSS Lead States, 2013b) describe progressions for each of the DCIs and SEPs across the grade bands K-2, 3-5, 6-9, and 9-12. These progressions were used to identify appropriate levels and sequencing of nodes.

Science literacy maps (http://strandmaps.dls.ucar.edu/, AAAS, 2015) are based on maps developed by project 2061 at the American Association for the Advancement of Science (AAAS). According to AAAS (2001), researchers and teams of teachers developed the science literacy maps based on assessment goals from *Benchmarks for Science Literacy* (AAAS, 1994), cognitive research, and definitions of adult science literacy from *Science for All Americans* (Rutherford & Ahlgren, 1991). Many teachers reviewed the maps (AAAS, 2013). These science literacy maps show how science concepts build upon one another across grade levels and illustrate the interconnectedness of science concepts. Sections of the science literacy map were used in combination with literature synthesis to build science learning map models.

Cognitive psychology literature provided studies of very young children's preacademic knowledge of some science concepts, as well as examples of how this knowledge was observed. This literature was used to develop additional nodes in the foundation area of the learning map models to address topics not included in the existing map (e.g., infants' knowledge of properties of animates), as well as to develop early nodes in the science learning map models that were needed to connect the foundation map to the science map.

In summary, the process consists of the following steps for each EE:

1. Define the region to map in the neighborhood by reviewing NGSS resources and reducing complexity to match the map boundaries better to the EE
2. Become familiar with DCI and SEP progressions that support the EE
3. Review materials that describe how students learn the DCI and SEP for the EE from birth to grade level understandings
4. Develop a research synthesis (i.e., narrative) that describes student learning from preacademic to high school
5. Create nodes and connections that reflect the research synthesis, fitting the SEPs and DCIs together in a more synthesized way.

Neighborhood Map Development Example

The following example illustrates the process used for map building for EE.5.PS1-3, "Make observations and measurements to identify materials based on their physical properties."

We defined the region to map after examining NGSS resources. From the NGSS (NGSS Lead States, 2013a), we identified and used the relevant sub-ideas within the DCI and SEP that corresponded to the EE as boundaries. The components are topics within each DCI. Boundaries are statements included in NGSS performance expectations that describe the content to include or exclude. We identified science learning progressions that support this EE. For example, a large body of literature exists describes student understandings regarding the

DCI *PS1.A Structure and Properties of Matter* (e.g., AAAS, 2015; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Rogat et al., 2011; Smith, Wiser, Anderson, & Krajcik, 2006; Wiser, Frazier, & Fox, 2013). Analysis of this literature showed that to reach the Target linkage level, "Make observations and measurements to identify materials based on physical properties," required two science content progressions. These science content progressions were integrated into the learning map model as described in the following paragraphs.

One science content progression describes general education students' learning about properties. Conceptual stepping stones are states of student knowledge that are significantly different than the prior state and represent a conceptual reorganization in students' thinking (Wiser, Frazier, & Fox, 2013). In the first conceptual stepping stone, K-2 students learn about characteristic properties observed with the senses (i.e., SCI-119). The next stepping stone for grades 3-5 further elaborates on this idea by including properties that are not readily observable with the senses, such as flammability and melting point (i.e., SCI-120 and SCI-121). These conceptual stepping stones, which provide a large-grained view of how general education students' understanding of properties of matter develops over K-5, have been translated into a finer-grained progression of nodes. As students' knowledge of properties develops, the ways they distinguish among objects, materials, and substances become more sophisticated.

The other science content progression describes students' developing understanding of how to distinguish between materials. In grades K-2, students identify objects by observable properties, kind of material, and object function (i.e., SCI-151, SCI-117). In grades 3-5, students understand that materials have characteristic patterns of relevant, common sense, observable properties, and that materials are more likely to be the same if they share multiple properties (i.e., SCI-138). This knowledge is needed to reach the Target level, in which students "make observations and measurements to identify materials based on physical properties." As students gain experience with and understanding of materials and their properties, they develop the understanding that some kinds of properties are characteristic of a material, while other kinds of properties are not (i.e., SCI-129). This understanding allows them to identify materials from a set of properties that includes intrinsic and extrinsic (i.e., non-inherent) properties of substances.

We searched the AAAS science literacy maps for content relevant to the DCI and SEP. Each node in the proposed model is cross-referenced to a node in the AAAS science literacy map to provide a check for appropriate level and order. When the level of nodes in the AAAS maps (AAAS, 2007) differed from those indicated in the *NGSS* (NGSS Lead States, 2013), we used the more recent conventions. For example, in some instances, content was introduced earlier in the NGSS than in the AAAS maps, and we used the grade-band assignment from the NGSS in the I-SMART maps.

The SEP for this neighborhood is *Planning and Carrying Out Investigations.* For this EE, the focus is on making observations of physical properties to identify materials. Science nodes describe a progression from recognition of common properties to identification of progressively more complex properties. As material properties grow more complex, how students identified the properties become more complex. For example, early in the neighborhood properties are determined with the senses (SCI-119), followed by the use of appropriate science tools (SCI-

120), and later by the use of various simple tests (SCI-121 and SCI-192). In another region of this neighborhood, students compare weight by sensory perception and description (SCI-207), then with a simple scale (SCI-208), and later with appropriate measuring tools and formal units (SCI-111).

Findings from the extant research were synthesized and summarized in a research narrative (Appendix). Research narratives describe student learning relevant to the EE during five grade bands: preacademic, K-2, 3-5, 6-8, and 9-12. The EEs increase in complexity across grade bands, and as such, nodes may overlap between map neighborhoods. Neighborhood nodes were created by representing both the content and practices. We created nodes that align to a DCI, to a SEP, or to a skill that is representative of the use of a SEP focused on specific DCI content.

Each I-SMART map used a DLM science map as a basis and extended the existing neighborhood by making adding or refining existing science content nodes and connections and adding appropriate connections to nodes in the ELA, mathematics, and foundations learning map models. Grade-level DCIs and SEPs have origins in the foundational, ELA, and mathematics maps. Staff searched these other maps for potential precursor KSUs for the nodes in the science neighborhoods. They developed new nodes in the foundation area learning map models to address foundation topics not included in the existing map (e.g., infants knowledge of properties of animates). For example, before students can make observations and measurements of physical properties, they need to understand how to observe those properties. These properties are qualitative at this level and described with words. Therefore, students understandings of descriptive words are important to this SEP. Nodes on the extant learning map, such as *F-105 Names things or people in the immediate environment* and *ELA-669 Provide real-world connections between words and their use* are part of the development of the SEP (Figure 2). We conducted an internal review of the proposed connections before finalizing the connections. Internal reviewers included staff at the center for Accessible Teaching, Learning and Assessment Systems (ATLAS) who represented a variety of disciplinary backgrounds, including experts on alternate assessment, special education, test design, science teaching, and psychometrics. Internal reviewers read and evaluated the research narrative for each neighborhood map and met with the principal map developer to review nodes and connections and offer feedback. Staff incorporated revisions from internal reviews into the draft maps before external reviews.

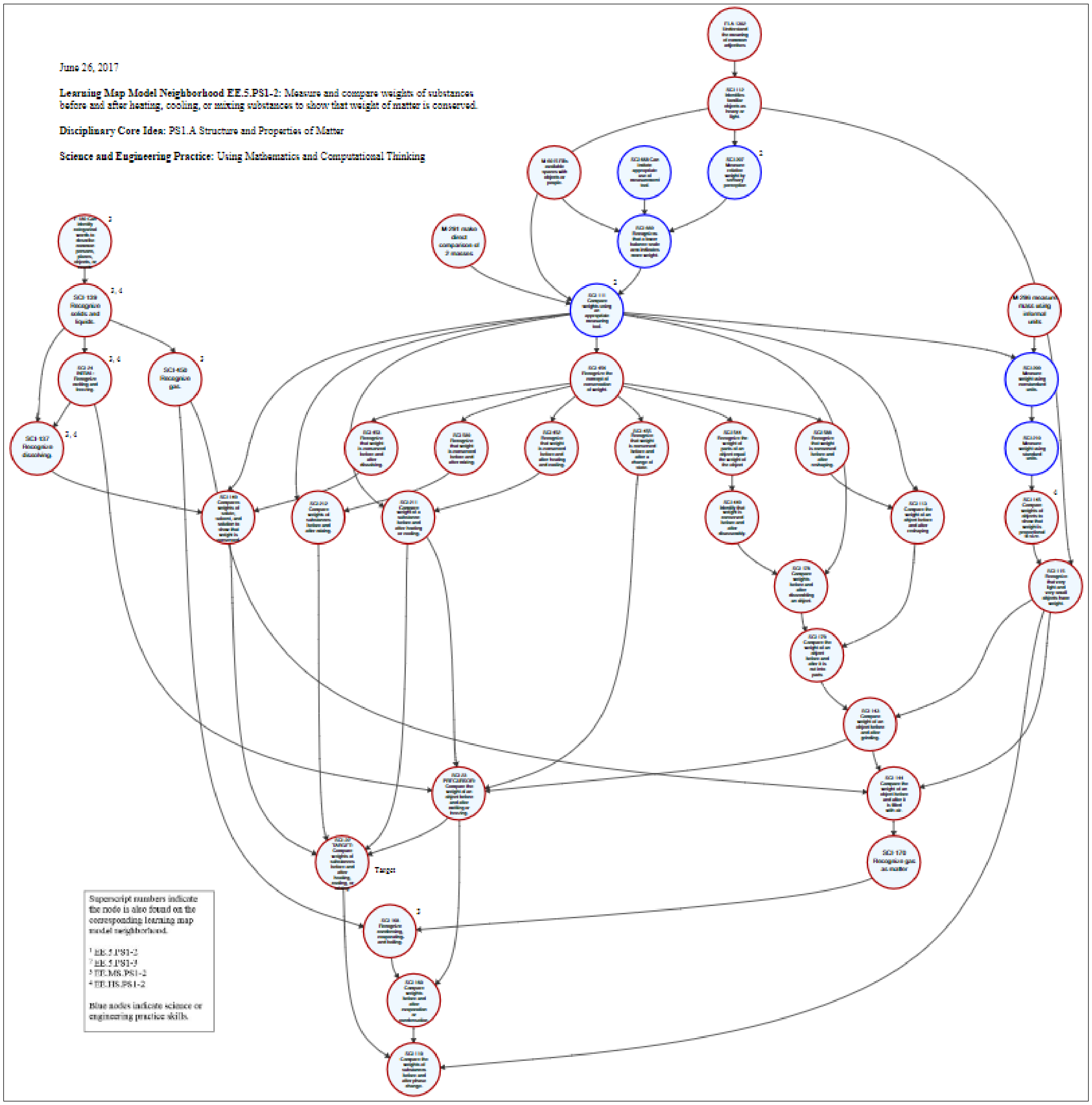


Figure 2. Learning Map Model Neighborhood EE.5.PS1-2

I-SMART Preliminary Map Development Summary

Map development work resulted in 11 preliminary I-SMART learning map model neighborhoods and research narratives to accompany each neighborhood. Neighborhood maps included between 32 to 52 nodes and between 36 to 83 connections with a total of 464 nodes and 695 connections (Table 1).

Table 1

Learning Map Model Neighborhood Content Prior to Review

EE	Nodes	Connections
EE.5.PS1-2	40	61
EE.5.PS1-3	32	40
EE.5.LS2-1	41	66
EE.5.ESS3-1	50	86
EE.MS.PS1-2	49	76
EE.MS.LS2-2	41	66
EE.MS.ESS3-3	45	65
EE.HS.PS1-2	40	50
EE.HS.LS2-2	52	83
EE.HS.ESS3-2	42	72
EE.HS.ESS3-3	42	62
Totals	474	727

I-SMART External Review Process

Purposes of the review. The main goal of the review process was to gather validity evidence for each learning map model neighborhood by having science and special educators evaluate the maps and make suggestions for revisions so that project staff could refine the models based on expert feedback. Specifically, we wanted to know how well the previously described node and connection criteria were met to ensure the accuracy of the DCI and SEP content progressions and the thorough application of UDL principles in each neighborhood map. The validity evidence comprised panel evaluations of how well the nodes and connections met the design criteria.

Additionally, as part of this process, we gathered evidence on (1) how the complexity of science content compared to ELA and mathematics content from the same grade band (i.e., horizontal relationships) and (2) the continuity of science content progressions across grade bands (i.e., vertical relationships). A secondary goal was to gather input from panelists on the *superhighway* of nodes and connections within the neighborhood map that represented a typical instructional pathway for the EE. From within that superhighway, we identified nodes that could be assessment targets in Goal 2 of the I-SMART project which involves the development of innovative, map-based science assessments.

At a panel review meeting, 11 neighborhoods were reviewed by three panels, with one panel for each grade band (elementary, middle, and high school).

Criteria used as part of the review process. We developed criteria for four kinds of evaluations participants would use during the panel review: (1) nodes and connections, (2) global neighborhood evaluation, (3) horizontal relationships, and (4) vertical relationships. First, the criteria for the evaluations of individual neighborhoods are presented, followed by the criteria for relationships between or among neighborhoods.

Individual neighborhood evaluations

Nodes and connections within each neighborhood. We adapted the review criteria used to evaluate the nodes and connections in each neighborhood from previous learning map model development work for the DLM Science Alternate Assessment (e.g., Andersen & Swinburne Romine, 2018). The node and connection review criteria are concise statements of the design criteria for learning map model neighborhoods that we have refined over multiple iterations of external review (Andersen & Swinburne Romine, 2018). Three criteria are specific to content review (i.e., the accuracy of DCI and SEP content) and four are specific to accessibility review (e.g., application of UDL principles). Adaptations were made to address differences in the intended populations for the DLM and I-SMART projects, such as changing “students with the most significant cognitive disabilities” to “all students” in accessibility criteria 1 and 3. An additional global neighborhood evaluation criterion was created to evaluate the overall accessibility of each neighborhood. The review criteria for nodes and connections for content, accessibility, and a global neighborhood evaluation criterion are in Table 2.

Table 2

Node and Connection Criteria

Category	Content Criteria	Accessibility (UDL) Criteria
Node	1. There is a clear relationship between the node and the Essential Element.	1. The node content is accessible to all students.
	2. The node size is appropriate.	2. The node content is free from significant barriers for students with sensory impairments, limited mobility, or limited communication.
Connection	3. The connection is accurate.	3. The connection represents an appropriate learning sequence for all students. 4. The connection describes a logical learning sequence for students with sensory impairments, limited mobility, or limited communication.
Global Criterion	The neighborhood provides content that is accessible and appropriate for all students in this grade band.	

Between and among neighborhoods evaluations. Staff created new criteria to evaluate the horizontal relationships across content domains (Table 3). These criteria were designed to help panelists evaluate how the complexity of science content compared to the ELA and mathematics content in the same grade band.

Staff created new criteria to evaluate vertical relationships within DCIs (Table 3). These criteria were designed to help panelists evaluate the continuity of science content progression across grade bands.

Table 3

Horizontal and Vertical Relationships Criteria

Criteria	Description	
	Horizontal Relationships Criteria	Vertical Relationships Criteria
Criterion 1	The neighborhood describes content that is similar in complexity to the selected ELA and mathematics mini maps in this grade band.	The neighborhoods increase in complexity to describe how students can progress from one grade band to the next.
Criterion 2	The neighborhood describes content that provides multiple points of instructional access for students.	The neighborhoods overlap sufficiently.

Materials used in the review

Before the review meeting, panelists were provided the research narrative for each neighborhood to review. The narratives presented the research synthesis that guided the construction of the neighborhood and described the development of the critical KSAs supporting the acquisition of the EE.

Table 4 shows the total nodes and connections included in the 11 draft neighborhood maps. Each map had a combination of unique nodes and connections, and nodes and connections shared with other neighborhood maps.

Table 4

Total Unique Nodes and Connections Evaluated

Neighborhood	Unique Nodes	Shared Nodes	Unique Connections	Shared Connections
EE.5.ESS3-1	27	23	61	25
EE.5.LS2-1	16	25	39	27
EE.5.PS1-2	31	9	55	6
EE.5.PS1-3	13	19	23	17
EE.HS.ESS3-2	28	24	51	21
EE.HS.ESS3-3	4	38	16	46
EE.HS.LS2-2	37	14	75	8
EE.HS.PS1-2	21	19	33	17
EE.MS.ESS3-3	26	19	44	19
EE.MS.LS2-2	17	24	39	27
EE.MS.PS1-2	26	23	50	26
Total Unique Nodes (only occurring in 1 neighborhood)	246		486	
Total Nodes Across All Neighborhoods	346			

At the meeting, we provided panelists with node and connection books for each neighborhood that provided the ID, name, description, and observation for each node in the neighborhood (Figure 3 and Figure 4). The books also listed the node ID and node name for the origin and destination nodes of each connection in the neighborhood.

Node ID	**Node Name**	**Node Description**	**Node Observation**
SCI-151	Identifies common materials.	Identifies common materials (e.g., common liquids, irregular shaped aggregates, or gels, such as water, milk, sand).	When asked "What's that?" about an irregular shaped aggregate, gel, or liquid, the student names the material.

Figure 3. Node Book Example

Origin Node ID	Origin Node Description	Destination Node ID	Destination Node Description
SCI-675	Demonstrates implicit awareness of pollution.	SCI-597	Recognize pollution.

Figure 4. Connection Book Example

Each panel had a poster-sized copy of each learning map model neighborhood for markup and to facilitate group discussion (Figure 5). The poster was labeled with the EE, DCI component, and SEP component. Nodes that overlapped with other neighborhoods in the same DCI had annotations with corresponding superscripts.

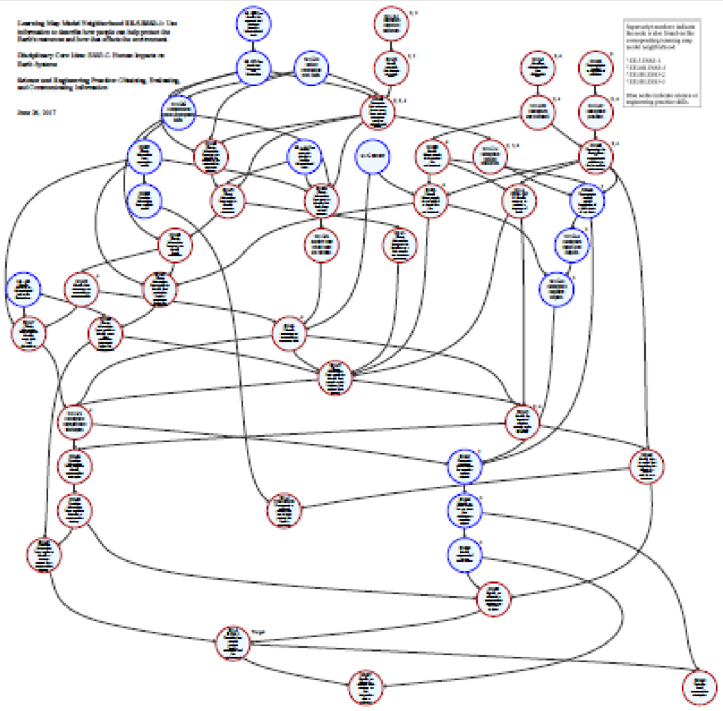


Figure 5. Learning Map Model Neighborhood Poster Example

Panelist Recruitment/Demographics. We recruited panelists from I-SMART partner states. General selection criteria included combinations of experience teaching science, special education, and familiarity with the NGSS. We also considered certifications, specific experience, and diversity of panelists for both content panelists and accessibility panelists. We recruited twelve teachers, and ten participated in the map review, with two withdrawing before the meeting due to unforeseen circumstances. Of the ten participants, three panelists came from Maryland, Missouri, and Oklahoma, and one panelist came from New Jersey. Eight panelists were classroom teachers, and two were district staff members. Six panelists described themselves as white/Caucasian, and four panelists described themselves as black/African

American. For science teaching experience, one panelist had less than a year, five panelists had between one and five years, one panelist had between six and ten years, and three panelists had eleven or more years. Two rural, six suburban, and one urban teacher participated.

Panel Facilitators. Project staff not primarily responsible for the creation of the draft maps acted as facilitators. All facilitators had experience leading panel processes for a variety of review and assessment development events. We developed a facilitator guide and provided training before the event to ensure smooth management of the panel process at each table. Facilitators were trained on the panel process, facilitation techniques, and the specific content for their panel review.

Rating Procedures

Each facilitator used an Excel spreadsheet to gather information during the review. Facilitators recorded each panelist's evaluation for every node and connection in the spreadsheet, as well as consensus decisions and recommendations. Facilitators also recorded ratings, rationales, and recommendations for other evaluations made by the panels in the spreadsheet.

Each panel reviewed the learning map model neighborhoods for one grade band. Facilitators led a four-step process through which each node and connection was evaluated using the node and connection criteria (Figure 6). The four-step process consisted of (1) individual ratings, (2) table discussion and panel recommendations, (3) panel horizontal evaluation of comparable ELA and mathematics mini maps and identification of the major learning pathway that the typical student would follow. Additionally, we intended for the middle school panel to collaborate with both elementary and high school panelists to evaluate the vertical relationships between science maps (in the same DCI).[1] Facilitators supported discussions that allowed the panels to arrive at consensus ratings, while also recording the group's rationales and recommended revisions.

Panelists recorded the ratings of each node and connection for each criterion, along with their rationale and revision suggestions on individual rating sheets (Figure 6).

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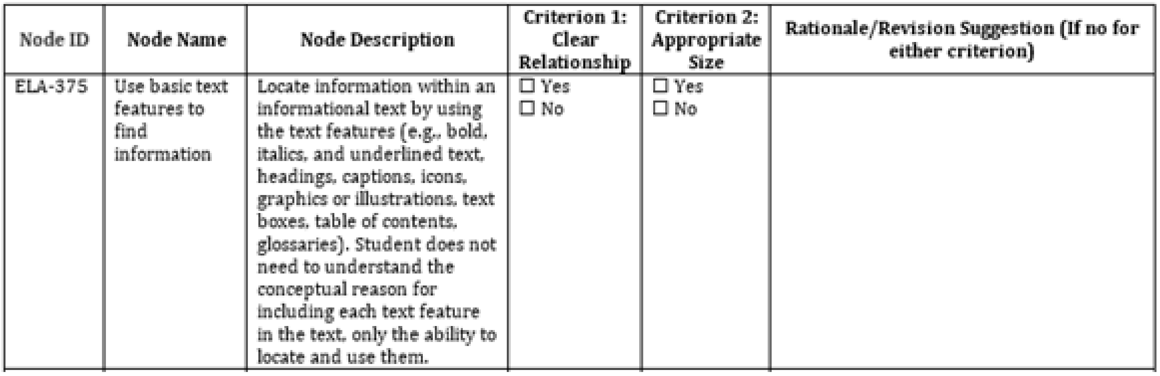
[1] At the external review event, only the middle school panelists completed their assigned neighborhoods leaving enough time to evaluate vertical relationships. The middle school panel reviewed the vertical relationship between 5.PS.1-2, MS.PS.1-2, and HS.PS.1-2, all of which had been completed by their respective grade level panels. Panel decisions related to global, horizontal and vertical relationships are shown in Table 3.



Node ID	Node Name	Node Description	Criterion 1: Clear Relationship	Criterion 2: Appropriate Size	Rationale/Revision Suggestion (If no for either criterion)
ELA-375	Use basic text features to find information	Locate information within an informational text by using the text features (e.g., bold, italics, and underlined text, headings, captions, icons, graphics or illustrations, text boxes, table of contents, glossaries). Student does not need to understand the conceptual reason for including each text feature in the text, only the ability to locate and use them.	☐ Yes ☐ No	☐ Yes ☐ No	

Figure 6. Individual rating sheet example

Training. Panelists completed two hours of advanced training consisting of two online modules that provided an overview of learning map models and the review process. Before the meeting, the panelists also reviewed the research narratives that provided summaries of the research on the topics covered in the learning map neighborhoods that they would review. At the meeting, panelists received one hour of on-site training about learning map concepts and the details of the review process. Next, each panel completed a practice review activity to become familiar with procedures, materials, and resources.

Results

Nodes and connections within each neighborhood. Overall, panelists evaluated 473 nodes and 710 connections within 11 neighborhoods. Results of the panel review are presented for each neighborhood and grouped by grade band in Table 5 and Table 6. Across all 11 neighborhoods, there was substantial variation in the number of nodes and connections that met criteria. Fifty-two to 100 with a median of 91 percent of nodes met criteria, while 67 to 97 with a median of 88 percent of connections met criteria.

Table 5

Panel Review Summary – Final Consensus Recommendations on Nodes and Connections by Neighborhood

Neighborhood	Nodes that met criteria	%	Connections that met criteria	%
EE.5.PS1-2	38	95	53	87
EE.5.PS1-3	29	91	36	90
EE.5.LS2.1	41	100	63	95
EE.5.ESS3-1	43	86	71	83
EE.MS.PS1-2	46	94	68	89
EE.MS.LS2-2	39	95	58	88
EE.MS.ESS3-3	43	96	63	97
EE.HS.PS1-2	29	73	24	48
EE.HS.LS2-2	27	52	59	71
EE.HS.ESS3-2	30	71	57	79
EE.HS.ESS3-3	29	69	56	90
Totals	394	83	608	84

By grade band, Table 6 shows that the percentages of nodes and connections that met criteria were fairly consistent within grade bands. However, the percentages of nodes and connections that met criteria were considerably lower for high school than for elementary and middle school, likely due to the increased complexity of map content and potentially more technical expertise of high school panelists.

Table 6

Panel Review Summary - Final Consensus Recommendations on Nodes and Connections by Grade Band

Grade Band	Nodes that met criteria	%	Connections that met criteria	%
Elementary	134	82	223	88
Middle	128	95	189	91
High	115	65	196	71
Total	393	83	608	82

Between and among neighborhood evaluations. Following the evaluation of the individual nodes and connections, the panels evaluated the learning map model neighborhoods on the quality of the global neighborhood. Specifically, they determined whether the neighborhoods provided accessible and appropriate content for all students in the grade band. The panels verified that the majority of the neighborhoods contained both accessible and appropriate content for all students (Table 7). However, they expressed some concern about an elementary school neighborhood. Their concern pertained to the lack of emphasis placed on certain areas of the neighborhood crucial to the acquisition of the EE and the inclusion of seemingly irrelevant nodes, which would make it difficult for teachers to use and understand the content. During the post-review panel process, the panel recommended the neighborhood be trimmed to include only the most important nodes for the EE. Overall, the majority of the learning map model neighborhoods contained accessible and appropriate for all students.

Following the global neighborhood evaluations, the panels evaluated the learning map model neighborhoods regarding their horizontal relationships with other content areas. For horizontal relationships, they examined the neighborhoods on whether they depict similarly complex content as represented in sections of the ELA and mathematics learning map models for the same grade band and whether they provide multiple instructional access points into the content (Table 7). For the first criterion, the panels determined that there was no significant difference in the complexity of the content represented in the three content areas. However, they judged that the content of the middle school science neighborhoods contained slightly less complex content than the mathematics section. For the second criterion, the panels concluded that the science neighborhoods provided multiple access points for instruction. In summary, the panels produced favorable evaluations on the horizontal relationships of the learning map model neighborhoods.

In addition to their horizontal relationships, the panels also examined the learning map model neighborhoods on their vertical relationships across grade bands. Specifically, they determined whether the neighborhoods representing the same topic increase in complexity and sufficiently overlap across consecutive grade bands, thereby providing an accurate depiction of student learning over time. Due to time constraints, the panel reviewed only one set of neighborhoods on their vertical relationships. For the four neighborhoods reviewed, the panel determined that the nodes gradually increased in complexity across grade bands and the neighborhoods sufficiently overlapped in their content, allowing the panel to follow student learning across the neighborhoods. However, the panel did suggest the inclusion of additional nodes from preceding neighborhoods to increase the overlap further. Although a lack of information prevents any firm conclusions from being made, the available information suggests that some of learning map model neighborhoods are related vertically in their content.

Table 7

Learning Map Model Neighborhood Evaluations Following Steps 1 and 2

EE	Global Neighborhood	Horizontal Relationships	Vertical Relationships
EE.5.PS1-2	Accept	Accept	NA
EE.5.PS1-3	Accept	Accept	NA
EE.5.LS2-1	Accept	Accept	NA
EE.5.ESS3-1	Revise	NA	NA
EE.MS.PS1-2	Accept	Mixed	Accept
EE.MS.LS2-2	Accept	Mixed	NA
EE.MS.ESS3-3	Accept	Mixed	NA
EE.HS.PS1-2	Accept	Accept	NA
EE.HS.LS2-1	Accept	Accept	NA
EE.HS.ESS3-2	Accept	Accept	NA
EE.HS.ESS3-3	Accept	Accept	NA
Totals	10 (91%)	7 (64%)	1 (9%)

Post-Panel Review Process

After the panel meeting, I-SMART staff reviewed the recommendations and accepted those that met criteria for logic, consistency with the neighborhood map, and consistency with the research narrative that supports the map (step 1). When staff was not certain whether the recommendations met the intended criteria or wanted to bring the recommendations forward for group discussion, they set them aside for a staff discussion (step 2). Staff forwarded 63% of recommendations for consideration at step 2. Of those evaluated during the step 2 meeting, staff accepted 32% by consensus decision. Table 8 summarizes the results of this process for the 11 learning map model neighborhoods, grouped by grade band. High school panelists recommended more revisions than elementary and middle school panelists, while staff accepted a larger percentage of the elementary and middle school panelists' recommended revisions than the high school panelists' revisions at Step 1. Of the recommendations forwarded to Step 2, staff rejected larger percentages of these for elementary and middle school and accepted larger percentages for high school.

Table 8

Post-Panel Review Summary by Grade Band

	Grade Band					
	Elementary		Middle		High	
	Nodes n %	Connections n %	Nodes n %	Connections n %	Nodes n %	Connections n %
Reviewed by panel	163	253	135	207	176	277
Panel recommended revisions	12 (7%)	26 (10%)	6 (4%)	18 (9%)	60 (34%)	58 (21%)
Revisions accepted	6 (50%)	10 (38%)	4 (67%)	9 (50%)	21 (35%)	17 (29%)
Revisions forwarded to step 2	6	16	1	9	39	41
Revisions rejected	6 (100%)	12 (75%)	1 (100%)	7 (78%)	18 (46%)	35 (85%)
Revisions accepted	0	4 (25%)	0	2 (22%)	21 (54%)	6(15%)

I-SMART staff coded the accepted recommendations using a categorization system developed for the Enhanced Learning Maps project. This categorization system was developed to indicate the rationale behind any changes made in the learning map model. It includes three categories of node changes (i.e., editorial, conceptual/semantic, and structural) and one type of connection change (i.e., structural). Editorial changes include adjustments to node name, node description, or node observation that preserve the basic skill and its placement. Conceptual/Semantic changes are changes that affect the representation of the skill, which may include changes to adjust node size (without separating or combining nodes) or changes that make assessing the node more practical. Structural changes include those that separate, combine, add, or delete nodes and connections, which affect how a section of the learning map model represents knowledge or skill development. Overall, 84.4% of node changes were editorial, and 15.5% were structural, while 80.7% of connection changes were additions and 19.3% were deletions.

After the review, we integrated the accepted changes into the 11 learning map model neighborhoods. Table 9 summarizes the changes that were made by neighborhood. The final neighborhoods had a total of 485 nodes and 740 connections. We added a total of 12 nodes, deleted no nodes, and revised 64 nodes while adding 44 connections and deleting 12 connections. Following the review, the number of nodes per neighborhood ranged from 32 to 52 with a median of 43, and the number of connections ranged from 40 to 87 with a median of 66.

Table 9

Learning Map Model Neighborhoods after Step 2

EE	Nodes	Node Changes			Connections	Connection Changes	
		Adds	Deletes	Revisions		Adds	Deletes
EE.5.PS1-2	42	2	0	0	66	7	2
EE.5.PS1-3	32	0	0	2	40	0	0
EE.5.LS2-1	41	0	0	4	66	2	2
EE.5.ESS3-1	50	0	0	5	86	1	1
EE.MS.PS1-2	49	0	0	3	75	1	2
EE.MS.LS2-2	44	3	0	5	70	5	1
EE.MS.ESS3-3	45	0	0	1	65	0	0
EE.HS.PS1-2	41	1	0	7	54	5	1
EE.HS.LS2-2	52	0	0	13	87	5	1
EE.HS.ESS3-2	47	5	0	12	85	14	1
EE.HS.ESS3-3	43	1	0	12	65	4	1
Totals	486	12	0	64	759	44	12

Evaluation of I-SMART Map Development

During the review meeting, the I-SMART map review process was evaluated both internally and externally on the processes and procedures used to review the learning map model neighborhoods. A project staff member with expertise in learning map model development across subjects served as an internal evaluator and recorded each table's conversations during the review process and observations of the entire meeting. The internal evaluator identified characteristics of the I-SMART map review processes that improved both the quantity and quality of the information collected regarding the content and accessibility of the science neighborhoods. Also, Bruce Yelton, the project's external evaluator, observed the panel meeting and conducted a focus group at the conclusion of that meeting. The purpose of the focus group interview was to gather data to answer research Question #1 of the project evaluation: *Is a* *cognitive map model to describe student science learning produced?* It was specifically designed to address the effectiveness of the review process from the participant viewpoint.

The internal and external evaluators provided favorable conclusions on the I-SMART map review process. Findings from the focus group revealed that the participants generally had positive perceptions of their on-site experience (training, table facilitators, facilities, the maps developed, the potential impact on special education instruction) in reviewing and revising the neighborhoods. Also, the evaluations identified the following procedures and resources used in the I-SMART map review process as appearing to support the quality of the collected feedback:

- Providing panelists with extensive background on the research basis for each map neighborhood
- Using a standardized facilitator guide for table leaders to ensure consistency and thoroughness in procedures across tables and map neighborhoods
- Focusing the review on academic targets and both typical and alternate pathways, with possible alternate pathways already represented in the draft map neighborhoods
- Providing materials that support the panel procedures, including a flowchart to illustrate the entire review process, and full printed copies of information panelists might wish to refer to when making their ratings
- Using a practice activity that included ratings and consensus discussions before the panelists began their reviews
- Creating panels that include members responsible for either accessibility or content criteria, with independent ratings followed by a panel discussion that brought both perspectives together when making final judgments and recommendations
- Convening a vertical articulation panel with members from each grade band to evaluate neighborhoods across the elementary, middle, and high school EEs for continuity

Conclusion

Summary of results

This report described the process and procedures used by the I-SMART project to accomplish Goal 1: Develop and evaluated a learning map model for science. It described the steps used to develop integrated and accessible science learning map models and the expert review conducted to evaluate the learning map model neighborhoods. The results of the I-SMART map review process indicated that the nodes and connections in the science neighborhoods across grade bands satisfactorily met the content and accessibility criteria. The I-SMART staff then reviewed the panels' recommendations and accepted about a third of them outright, while the remaining recommendations required further discussion. Of the remaining recommendations, staff accepted about half, integrating them into their respective neighborhoods. The majority of the node changes were editorial, focusing on changes to node name, description, or observation while preserving the basic skill and its placement in the map. For connections, the changes mostly involved adding new connections to the neighborhoods. The I-SMART map review process also provided validity evidence suggesting that the neighborhoods 1) contained accessible and appropriate content for all students; 2) depicted the content of similar complexity as in other content areas; and 3) included multiple instructional access points into the content.

Evaluation of the Map Review Process

Standardized review procedures supported the fidelity of the panels' content and accessibility evaluations, and informing panelists of each step in the procedure, and its importance improved the panelists' motivation and self-efficacy. Additionally, focused evaluations according to knowledge and experience within an informative context of a science neighborhood allowed panelists to make informed decisions regarding the quality of the nodes and connections. Including both individual and group evaluations in the review process increased the amount of quantitative evidence collected on the quality of the nodes and connections in a neighborhood and allowed the panels to reach a consensus on their content and accessibility using their diverse breadth of expertise. Furthermore, having panels evaluate the vertical relationship of neighborhoods targeting the same topic across grade bands ensured that student learning was continuously represented from the foundational skills that precede academic content through high school academic content. Finally, the panelists who are experts in the science content experts or on the target student populations are in the best position to determine the learning pathway used by a "typical" student for a given topic.

Lessons Learned and Future Improvements

The evaluation of the I-SMART map review process produced multiple important lessons that we apply to the design of the procedures used in future reviews of learning map model neighborhoods. These lessons target panelist readiness for the review meeting (e.g., clarifying the requirements of advance training), common panelist misconceptions to facilitate the rating process and the interpretation of panel review input. Some potential refinements generated by the external evaluation, conducted by BYC consulting, of the map review process are listed below.

- Expanding node observations to include examples of how students with different characteristics and abilities may demonstrate their learning
- Piloting advance training protocols to ensure that the information is easily accessible and provides enough context for the task (i.e., specific EEs to be addressed, the relationship of the task to the larger learning map design)
- Emphasizing to panelists the expectation that they should read the research narratives as part of training before arrival at the panel meeting
- Extending initial orientation/training to include a similar group task that will answer questions about the task and establish rapport with the facilitators/specialists
- Addressing teachers' practical classroom experiences and demands (e.g., assessment, individualization for particular student challenges) in presenting and completing the task
- Expanding training on the use of specific vocabulary, especially verbs, that may be used in the I-SMART project in a way that differs from teachers' varied interpretations of the terms (e.g., cognitive processes such as "recognize")
- Helping panelists develop a deeper understanding of learning map models in general (e.g., prerequisite versus precursor nodes, the meaning conveyed by the location of a node on the page, and the meaning of parallel nodes)
- Emphasizing to panelists the importance of node observations and the surrounding context in the neighborhood when making recommendations about similar-looking nodes

- Emphasizing to panelists that their personal experiences with specific students should inform but not delimit their views on accessibility
- Clarifying the relevance of rating criteria applicable only to a subset of the content to be evaluated (e.g., alignment of the node to EE)

  Being accepting of panelist questions and understanding that the task is complex, intense, and tedious

ATLAS staff have considered the external evaluation feedback and applied it to other projects in the center that focus on similar training and review events. Additionally, staff has applied some of the lessons learned have in the subsequent I-SMART work on designing and reviewing innovative science assessments based on the maps described in this report.

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