A Design Inquiry: Bridging Assessment and Curriculum Frameworks to Engage Students in Science Practices

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Abstract: This reflective inquiry delves into the collaborative design process of a technology-based middle school genetics unit. With a lens on science practices, we describe how bridging assessment and curriculum design frameworks can inform decisions in an iterative co-design process. The paper explores the role of these design frameworks in articulating learning goals and outcomes, designing the learning experience to motivate student inquiry, and identifying features of technology tasks and tools to elicit artifacts and evidence. A pilot study with four teachers and 435 students revealed how to enhance elements of the design approach to strengthen the learning goals, improve learning experiences with visualizations, and streamline the flow of the curriculum to emphasize productive patterns of inquiry. Implications of this integrated approach for informing the design of learning environments, the scalability of designs, and teacher practice are discussed.

Introduction

Extensive research situates science education as a means for broadening participation in the practice and culture of science. Researchers have designed learning environments that present science as an important part of everyday life using relevant science dilemmas, engage learners in authentic scientific practices such as modeling and evidence-based explanations, and incorporate technology that helps students visualize scientific phenomena and monitor understanding (e.g., Bell, 2004; Lee, Linn, Varma & Liu, 2010; McNeil & Krajcik, 2011).

Despite the preponderance of evidence that suggests students learn science best through these rich experiences, school science has been reported to decontextualize science and require less rigorous learning performance. Limited resources, such as poor access to technology, too few professional development opportunities, and policies that endorse fragmented, low-level content standards, have challenged teachers' ability to offer coherent learning experiences for all students (Kali, Linn, & Roseman; 2008; Lee et al., 2010).

Well-designed, coherent materials have the potential to address the aforementioned challenges. With a lens on science practices, this paper describes how bridging assessment and curriculum design frameworks can inform key decisions in the iterative design process of a technology-based middle school genetics curriculum. We report emergent design knowledge aimed to help designers and researchers leverage resources in the (re)design, study, and scale of science learning environments that are accessible to schools and promote deep and meaningful science learning and teaching.

Theoretical Approach

Two frameworks guide our approach: Knowledge Integration and Evidence Centered-Design.

Knowledge Integration (KI)

Knowledge Integration (KI) offers a learning perspective and design framework to explain how students develop a deep understanding of science in everyday life and designed learning environments. KI recognizes that students maintain a repertoire of ideas about scientific topics, practices, and disciplines (Bransford, Brown, & Cocking, 2000; Linn, Davis, & Bell, 2004). As students learn through a variety of experiences in and outside school, they revise their repertoire by adding new ideas or changing the relation among new and existing ideas.

The KI design framework, comprised of *principles*, *processes* and *patterns,* guides the design of coherent science instruction, which provides students multiple opportunities to consider all their ideas, add scientifically sound new ideas, develop relations among these ideas, and promote an integrated understanding (Kali, Linn, & Roseman, 2008; Lee et al., 2010; Linn & Eylon, 2006). The *principles* (make science accessible, make thinking visible, help students learn from each other, and promote autonomous and lifelong learning) communicate the nature and quality of learning experiences that promote knowledge integration. The *process* (elicit ideas - add ideas - distinguish ideas - sort ideas) and *patterns* (e.g., predict, observe, create a model, explain) help designers coordinate learning activities that develop a deep understanding of science.

Evidence-Centered Design (ECD)

Evidence-centered design (ECD; Mislevy & Haertel, 2006) provides tools for creating valid assessments within learning environments. ECD involves an analysis of the substantive domain; the construction of an assessment argument; specification of tasks, rubrics and psychometric models; and the implementation and delivery of tasks within an operational assessment. A critical contribution of ECD is its provision of processes and structures to describe epistemic practices within disciplines. ECD facilitates the articulation of (1) learning goals (knowledge, practices, abilities and the integration thereof), (2) evidence produced in the form of actions by and among students, and (3) features of environments to elicit the desired evidence and learning goals. By making the underlying evidentiary argument for an assessment explicit, ECD facilitates coherence in assessment design. As technologies (e.g., visualizations and simulations) become further integrated in learning environments, ECD is critical for communicating decisions among the experts involved the design of these assessments.

Coordinating and Integrating KI and ECD

Our design approach aims to attend carefully to three dimensions: (1) learning goals that integrate core ideas, practices, and cross-cutting concepts within the discipline of science; (2) clear articulation of evidence, artifacts, and the ways students should engage to produce these; and (3) the features and flow of activity designs and participation structures. See Table 1. While KI prioritizes deepening students' understanding in a discipline through practice, ECD heightens awareness of assessment design within learning environments—how we know learning is taking place. Along these lines, KI and ECD function at different grain sizes in the design space.

Table 1: Mapping of KI and ECD Theoretical Approaches to Design Dimensions for Learning Environments.

	Design Dimensions		
	Learning Goals	Evidence, Artifacts and Engagement	Features and Flow of Activity and Task Designs
Knowledge Integration (KI)	Focus on connections between key ideas that promote lifelong learning	Learning as engagement through eliciting, adding, distinguishing, sorting ideas	Application of design patterns to promote knowledge integration within and across activities
Evidence-Centered Design (ECD)	Knowledge, practices, and abilities and combinations thereof that will be the target of assessments	Clear articulation of evidence produced by students to indicate progress toward and attainment of learning goals	Specification of activity and task design features to elicit desired evidence

We openly explored how KI and ECD approaches inform the design of a genetics unit, specifically addressing two questions: (1) What is the role of KI and ECD in articulating learning goals and outcomes? (2) How can KI and ECD help to define the learning experience and artifacts and elicit evidence of learning?

Project Context

The project context is the development and testing of a 5-week technology-based middle school genetics unit. Our goal is to develop students' understanding of inheritance through science practices of constructing models and explanations (see NRC, 2012). "*How can you use genetics to feed the world in 2052?*" is the driving question. The unit introduces a situation where the world will be running short of food and fossil fuels in 2052. Students inquire about how to selectively breed for more nutritious rice and higher endurance horses. Student pairs complete 10 activities with frequent opportunities for whole class discussion facilitated by the teacher using the open-source WISE 4.0 platform. Notable advantages of the WISE platform include tools such as *Idea Manager*, which supports sorting ideas and constructing explanations (McElhaney et al., 2012), and *WISE Draw*, a tool that students can use to draw models that illustrate a mechanism or process.

Initial Design Approach and Implementation

Our co-design process involved experts in curriculum design, assessment design, science content, science teaching and software design. We engaged teachers as co-designers, and these teachers served as mentor teachers to their colleagues during implementation of the unit. A key structure in facilitating conversation about flow was the unit template, which documents for each activity (1) learning goals addressed, (2) anticipated student problematic ideas, (3) learning experiences needed to address problematic ideas, (4) assessment opportunities, and (4) the KI design pattern sequence to motivate student inquiry in the activity.

Articulation of the Learning Goals and Outcomes

The design team referred to the *Framework for K-12 Science Education* (NRC, 2012) to identify disciplinary core ideas that comprise a deep understanding of inheritance for seventh grade students. The *Framework* also helped to unpack two science practices targeted by the unit: *Developing and Using Models* and *Constructing Explanations*. Here, we followed the ECD framework to specify abilities targeted for each practice as Knowledge Skills, and Abilities (KSAs; e.g., Ability to construct a causal explanation; Ability to construct a model and use the model to explain a phenomenon). The KI perspective helped establish 12 measurable learning goals that integrated content. The learning goals began with a broad statement about the core idea and science practice (e.g., *Students will be able to generate explanations that link the macro and micro structures/processes/functions relating to genetic expression*) with additional details about the content to be addressed (e.g., *An organism's characteristics can be expressed in different versions or variations called traits*).

Defining the Learning Experience, Artifacts and Evidence

KI prompted us to think about how to scaffold students to write integrated explanations of heredity and develop models. The design team identified WISE steps that engaged students in the knowledge integration process (i.e., elicit, add, distinguish, and sort ideas). For example, the Explanation Builder step guides students to *distinguish* which ideas help explain the genetic expression process. Using ECD, evidence for each of the practices was broadly specified in terms of *potential observations* we might expect to see if students are engaged in constructing models or explanations (e.g., application of science concepts to reason about the phenomenon).

Task Features and Flow

The KI design principles (e.g., make science visible) and patterns (e.g., *Predict-Observe-Explain* [POE]) informed an activity flow to scaffold coherent explanations of heredity. To *make the practices of scientists visible*, the activities require students to conduct selective breeding experiments using interactive visualizations. WISE Reflection Notes were then used to elicit students' predictions and post-observation explanations to *make students' scientific ideas visible*. ECD served to define specific design features of assessment opportunities as *characteristic features* or *variable features*. We considered which features needed to be present in tasks (e.g., All items that prompt for a scientific explanation will include data or evidence in stimulus materials) and documented how tasks might vary (e.g., the complexity of data/evidence).

Pilot Study

Four seventh grade science teachers implemented the unit in their classes for five weeks in Spring 2013; two teachers were from a school in a Midwest suburban district, and two were from a Southern suburban district. The Midwest school district student body is approximately 60% Caucasian, 18% African American, 9% Asian, 7% Hispanic, 5% Multi-racial and 1% American Indian and Pacific Islander. Twenty-five percent of the students are on free or reduced price lunch. The student body of the school district in the South is approximately 64% African American, 28% Hispanic, and 8% Caucasian. Sixty-one percent of the students are on free or reduced price lunch. 435 students from 19 classes participated in the study and worked in pairs. Prior to implementation, all teachers participated in a 2-day professional development workshop to discuss the unit learning goals, the activities and web-based tools, and the teacher interface to manage student data. Student work was logged by WISE system. The team also conducted regular classroom observations, and mentor teachers facilitated conversations with their colleagues during the implementation of the unit.

Sources of Data to Inform Revisions

Student work on assessments provided evidence of their thinking and reasoning. Memos from classroom observations and conversations with teachers provided insight into the student and teacher reactions to particular activities and factors that hinder implementation.

Findings

An analysis of student work revealed that on average, groups submitted four to five ideas while viewing visualizations and selected between three to seven ideas to support explanations. One fourth (24.7%) of the ideas were problematic and non-normative. For example, students struggled to link ideas about macro-level observed traits and micro-level cellular-level processes. Observations revealed that teachers' facilitation of prediction, modeling, and explanation steps was uneven. Some teachers engaged students in productive discourse around focal ideas in the unit (e.g., "Why do we want rice with high starch and horses with high endurance?"), but based on the observations, there was no evidence that these rich conversations occurred frequently. These findings demonstrated the need for additional support for teachers and students to promote knowledge integration. Revisions to the design approach are described below.

Revised Design Approach

Articulation of Focused Knowledge-In-Use Learning Goals and Evidence

We believed that students struggled to construct explanations and models that link ideas about macro-level observations and micro-level processes in part because our learning goals needed to be much more explicit in this regard. Using ECD, we refined the original 12 learning goals into five learning performances that more explicitly consider targeted applications of the science practices within genetics: (1) *Ability to use a model of trait expression to explain the observed traits in an organism*; (2) *Ability to construct a model of processes within a cell and use the model to explain how traits are expressed*; (3) *Ability to evaluate different models of trait expression*; (4) *Ability to construct a scientific explanation about how sexual reproduction can affect genetic variation*; and (5) *Ability to explain how sexual reproduction and expression results in trait variation*. For each learning performance, we crafted statements that clarify the evidence students would need to produce to demonstrate proficiency. See Table 2. The KI lens with ECD helped to outline the macro (e.g., identify observed trait) and micro (e.g., use the model to explain the mechanism of trait expression) elements.

Table 2: Example of Refined Learning Goal and Anticipated Evidence from Student Artifacts.

Learning Goal	Evidence in Student Artifacts
Ability to use a model of trait expression to explain the observed traits in an organism	Appropriate use of visualization (model) of gene expression to explain why an organism has a particular trait. Macro and micro elements are connected in the explanation. ● *Macro*: Identification the observed characteristic and trait ● *Micro-structural*: Identification of the location of the relevant component (s) of the cell ● *Micro-functional*: Description of the function of relevant component (s) of the cell ● *Micro-mechanistic*: Description of the mechanism of to explain trait expression

Designing a More Consistent and Coherent Learning Experience

The rearticulated learning goals and evidence statements prompted the design team to bring practices to the forefront and further realize the design principle, *make the practices of scientists more visible.* We first made the alignment of activity steps to KI patterns more transparent. Activity steps now more explicitly map on to aspects of science practices. For example, for the *POE* pattern, a Brainstorm step is used to elicit students' predictions in conjunction with the Idea Manager Tools (Idea Basket and Explanation Builder) to support students in documenting observations and constructing explanations. Applying ECD, we refined features of the Idea Basket steps to promote more active and focused observations of visualizations, as shown in Figure 1. Explanation Builder question prompts elicit more directly explanations that require links between micro- and macro-level ideas (e.g., *Explain what happens inside a rice plant that makes it high nutrition and how Farmer Wilder can check that the rice is very nutritious.*) For some activities we also extended the basic *POE* pattern to incorporate modeling (*Predict-Observe-Model-Explain [POME]* pattern). In the *POME* pattern, students create a dynamic visual model using the WISE Draw tool.

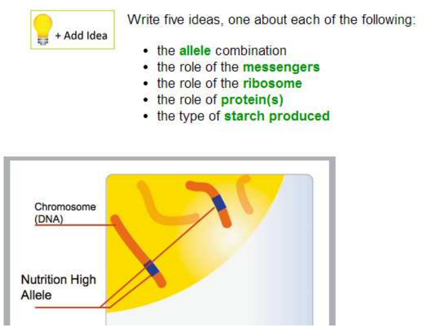

Figure 1. Screenshot of Expression Visualization with Idea Basket Prompts

Conclusions and Implications

Findings from this design study demonstrate that KI and ECD are complementary design perspectives. KI offers strong grounding around patterns to guide the flow of curricular experiences as well as a lens that focuses on designs promoting connected conceptual understanding in models/explanations. ECD bolsters design practices to support coherence in the rendering and application of tools to elicit intended knowledge and skills within a curriculum and facilitates the articulation of evidence to look for in student-generated artifacts.

The preliminary nature of our study limits our ability to generalize beyond the context of this unit. Yet, our early attention to emergent design knowledge positions us for a more rigorous investigation of student engagement and learning outcomes during a larger scale implementation study in the 2013-2014 school year. This paper lends insights to practical approaches for designing knowledge-in-use learning environments that engage students in important epistemological practices and incorporate valid assessments.

This approach also supports scalability and reuse of design principles. Generating design solutions not only involved conversations among the co-design team, but also clear documentation of decisions (e.g., new KI patterns and the unit template). These types of design documents afford the potential reuse of designs and scalability of assessments and tasks for related purposes. By explicating these decisions using shared schemas, other learning environments (e.g., game-based) that incorporate these science practices can subsequently be generated more easily by designers without having to retrace decision paths.

While teacher practice is not the focus of this paper, we highlight some implications of our approaches for teachers. We envision the curriculum and assessments as a starting point for discourse on constructing models and explanations. Thus, successful implementations of this unit and similar learning environments require supports for establishing norms to promote equitable participation (e.g., Hudicourt-Barnes, 2003), eliciting student reasoning and promoting discussion (e.g., Penuel, Beauvineau, DeBarger, Moorthy, & Allison, 2012), and using assessments to provide feedback to students (e.g., Ruiz-Primo & Furtak, 2007).

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