Evaluating Knowledge Community Curricula in Secondary Science Using Model-Based Design Research

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Abstract: This paper describes a new approach to design-based research that utilizes a formal model of learning, mapped onto the curriculum design, to assess when, where, why and how the enacted design is achieving or failing to achieve its aims. Model-based design research (MBDR) goes beyond testing whether a particular intervention 'works' or 'doesn't work,' allowing researchers to characterize each player within the learning environment, comparing their beliefs, actions, and artifacts with the epistemic aims and assumptions built into the model, and then iteratively refine the design. MBDR refers to a formal theoretical model as a source of design constraint, allowing researchers to identify and justify their choice of design elements and the linkages between them. However this approach goes one step further and adds a means of *evaluating* curriculum designs in relation to the model. Evaluation thus occurs on two levels: (1) How true was the design to the model; and (2) How true was the enactment to the design. This paper provides a detailed case study of MBDR, including the model that underlies the design, and the two analyses that comprise the study. We evaluate a new secondary biology curriculum that was designed according to the Knowledge Community and Inquiry model, evaluating the design and enactment of the curriculum according to the model, and conclude with a discussion and recommendations for new epistemic elements within the model.

1. Introduction

One domain of research that is highly relevant to 21st century learning is concerned with learning as a knowledge community (Brown & Campione, 1994; Scardamalia & Bereiter, 1999; Bielczyc & Collins, 2005), where students are given a high level of agency and responsibility for developing their own questions, exchanging and critiquing ideas with peers, and even evaluating their own progress. Teachers become members of the classroom knowledge community, and participate as peers and mentors. The students within a knowledge community typically create a "knowledge base" of commonly held resources or ideas, which are accessed, re-negotiated, revised and applied during subsequent inquiry activities. Community knowledge resources are captured and represented within a technology-mediated environment that scaffolds students as they add new ideas, revise materials, synthesize arguments or inform their designs (Stahl, 2000; Hoadley & Pea, 2002; Bielczyc & Collins, 2005).

This paper describes a new approach to design-based research that utilizes a formal model of learning, mapped onto the curriculum design, to assess when, where, why and how the enacted design is achieving or failing to achieve its aims. As with most design-oriented research methods, the proposed process, called model-based design research (MBDR), goes beyond testing whether a particular intervention 'works' or 'doesn't work.' Instead, it allows researchers to characterize each player within the learning environment, comparing their beliefs, actions, and artifacts with the epistemic aims and assumptions built into the model, and then iteratively refine the design such that 'progress' can be achieved in the design.

2. Model-Based Design Research

Since its inception in the early 1990s (Brown, 1992; Collins, 1992), design-based research has become a widely used and broadly accepted research paradigm in the learning sciences. This approach maintains a commitment to the creation and development of innovative learning environments by simultaneously engaging in design evaluation and theory building throughout the research process (Edelson, 2002). Design-based research typically includes three characteristics: (1) Systematic intervention into a specific learning context, accounting for factors such as the teachers, learners, curricular materials, and available technologies; (2) An interdisciplinary design team consisting of teachers, researchers, technologists, and subject-area specialists; and (3) Iterative design modification in which interim findings are used to improve the design throughout its implementation (Najafi, 2012; Edelson, 2002; Bell, Hoadley & Linn, 2004).

Bereiter (2002) highlights that design research is generally not defined by its methods but instead by the goals of those who pursue it. Those engaging in design research are generally committed to specific outcomes, including the development of innovative learning environments or curricula, the characterization of the specific contexts in which the learning designs are employed, as well as general knowledge about the fundamentals of teaching and learning (Sandoval, in press). However, despite its commitment to these research goals, design-based research has been criticized for lacking methodological rigor due to the absence of clearly defined methods and standards (Sandoval, in press; Dede, 2004; Kelly, 2004; Shavelson *et al.,* 2003).

Whereas the bulk of scholarly literature on design research within the past decade has focused on the *what* rather than the *how,* Sandoval has attempted to address these criticisms by formulating a methodological approach which he calls 'conjecture mapping' (Sandoval, 2004; in press). The purpose of conjecture mapping is to explicitly identify and make salient the specific relationships between a learning design and the theoretical conjectures that informed the design (Sandoval, 2004). Sandoval (in press) identifies three types of conjectures:

1. *High level conjectures* – the broad, theoretical, abstract "big ideas" or learning principles that are typically used to motivate or initiate the design process
2. *Design conjectures* – theoretical assertions that guide or constrain how particular design features or "embodiments" (e.g. tools and materials, task structures, participant structures, discursive practices) will yield particular mediating processes (e.g. observable interactions, participant artifacts)
3. *Theoretical conjectures* – theoretical beliefs or assertions that describe how the mediating processes of a design will yield particular outcomes (e.g. learning, interest/motivation, etc.)

By explicitly mapping such conjectures onto curriculum designs, researchers are productively required to articulate and justify their choice of design embodiments, mediating processes, outcomes, as well as the means and methods for tracing the linkages between them (Sandoval, in press).

In ways that are similar to conjecture mapping, MBDR refers to a formal theoretical model as a source of design constraint, allowing researchers to identify and justify their choice of design elements and the linkages between them. However this approach goes one step further and adds a means of *evaluating* curriculum designs in relation to the model. Evaluation thus occurs on two levels: (1) How true was the design to the model; and (2) How true was the enactment to the design. While MDBR is only applicable in cases where a formal structural model exists, and could be seen as a special case of conjecture mapping, it is nonetheless an interesting form of design-oriented research, particularly in the sense that the outcomes of an MDBR study can directly inform revisions or improvements to the underlying model. In sections below, we provide a detailed case study of MBDR, including the model that underlies the design, and the two analyses that comprise the study. We conclude with a discussion of the model, including recommendations for new epistemic elements of the model.

3. Case Study: Designing EvoRoom

3.1 The Model: Knowledge Community and Inquiry (KCI)

While knowledge community approaches, such as Fostering Communities of Learners (Brown, 1997) and Knowledge Building (Scardamalia & Bereiter, 2006) have been successfully implemented at the elementary level, current school structures and content-heavy curriculum demands often make those models inaccessible to course instructors – particularly at the secondary level. KCI is a pedagogical model that was developed for secondary science as a means of blending the core philosophies of the knowledge community approach with the structural and scripted affordances of scaffolded inquiry (Slotta & Peters, 2008; Slotta & Najafi, 2010). KCI includes five major design principles, each accompanied by a set of epistemological commitments, pedagogical affordances, and technology elements. Together, these guide the creation of inquiry activities, peer interactions and exchange, and cooperative knowledge construction. The five principles are summarized in Table 1.

3.2 The Design: EvoRoom, Grade 11 Biology Curriculum

Use of the word 'EvoRoom' is twofold. In one sense it refers to an actual room that was constructed using smart classroom technologies to simulate an immersive rainforest environment. When students enter this "smart classroom", their interactions – where they go in the room, and with whom – are carefully orchestrated, and depend on real-time ideas and observations that they enter into their tablets. Their ideas and collective efforts are made visible and accessible to everyone in the room through the use of a persistent aggregate display at the front of the room (see Figure 1). In the other sense of the word, 'EvoRoom' refers to a much broader 10-week curriculum for Grade 11 Biology that was designed to fulfill the requirements for evolution and biodiversity. This 10-week curriculum included an online learning portfolio (for which activities were completed both at home and at school); a zoo field trip; 'traditional' classroom lessons; as well as two unique activities completed within the EvoRoom itself.

Figure 1: EvoRoom: A room-sized immersive simulation where students interact with peers and with elements of the room itself (walls, table, tablets) to conduct collaborative inquiry in the domain of evolution and biodiversity).

Table 1: KCI Design Principles

Epistemological Commitments	Pedagogical Affordances	Technology Elements
1. Students work collectively as a knowledge community, creating a knowledge base that serves as a resource for their ongoing inquiry within a specific science domain.		
Students "identify" as a community, with the goals and purposes of learning together and advancing the community's knowledge. The knowledge base needs to be understood and valued as "their community resource."	The knowledge base is indexed to the targeted science domain as well as semantic and social variables; Semantic index variables can be designed, as well as user contributed or emergent	Tablets, wikis, semantic web, metadata schemes, science content standards, tagging schemes
2. The knowledge base that is accessible for use as a resource as well as for editing and improvement by all members.		
Knowledge building processes: improvable ideas, measurable or observable progress within the knowledge base, emergent content organization (i.e. semantic structure)	Scripts for jigsaw and collaborative knowledge construction; visualizations and interfaces for accessing the knowledge base; authorship attributions; versioning and forking	Socially editable media, wikis, notes, or collections of observations; social tagging; visualizations; recommender agents
3. Collaborative inquiry activities are designed to address the targeted science learning goals, including assessable outcomes		
Inquiry learning is fundamentally constructivist, where students build on their existing ideas to develop understanding. A social dimension of shared ideas, discourse and practice also underlies the design of collaborative inquiry.	Learner-centered and idea-centered activities, including critique, comparison, design and reflection. Students create artifacts, reflect on those artifacts, and apply them as resources within a larger inquiry project.	Web-based learning activities, wikis, Web portal, video editing, simulations, tablet-based observation forms, laptop and tablet interfaces
4. Inquiry activities are designed to engage students with the knowledge base as a resource, and to add new ideas and elements to the knowledge base		
Inquiry emphasizes the growth of individual ideas through reflection and application, but also a social connection, for discourse and collaboration	Need for open-ended activity designs, to connect to full index of knowledge base (i.e. to assure complete coverage), but also to respond to emergent ideas or themes within the community; possible dynamic grouping of students based on shared ideas, disagreements or other inquiry-oriented variables.	Specific technology tools and materials are developed to support inquiry activities. These adhere to a pedagogical "script" that defines the sequence or progression of activities, roles, groups, etc. Students may use a variety of technology-based learning environments, carefully designed to support the pedagogical script.
5. The teacher plays a specific role defined within the inquiry script, but also a general orchestration role, scaffolded by the technology environment		
The teacher's role is that of an expert collaborator or mentor, responding to student ideas as they emerge, and orchestrating the pedagogical flow of activities. The teacher must understand student learning as a collective endeavor, and must see his or her own role as that of an important community member.	The teacher engages in specific scripted interactions with students; providing feedback and making orchestrational decisions based on the content of student interactions and artifacts. The teacher is responsible for moving the inquiry forward through a progression of activities, but also plays specific roles within activities (talking with students, giving feedback, etc).	Teachers also rely on technology to help orchestrate the flow of activities. They may refer to representations of the aggregated community knowledge to inform reflective discussions (e.g., about what the 'next steps" should be, in inquiry). Or they may have specific technologies designed to support their interactions with students (e.g., a teacher tablet).

In order to ensure that the overall curriculum design, including all detailed activities, materials and interactions, was suitable for secondary biology in a high achieving school context, the teacher was a critical member of the design team. The teacher was highly involved in the development of the orchestrational scripts and technology elements that went into the design, and provided valuable feedback with regards to tool development and the overall curricular goals for the evolution and biodiversity units. The co-design team also consisted of two graduate researchers, three computer programmers, and one faculty supervisor.

At the time of this writing, the EvoRoom curriculum is just completing its third design iteration. The pilot run for EvoRoom was completed in June 2011; the second iteration was completed between December 2011 and February 2012; and the third (current) iteration was completed between March and May 2013. It includes a 10-week sequence of activities, where students participate in a wide range of classroom activities (including lectures and labs), create a shared classroom knowledge base, and conduct field trip and smart room activities that make use of their knowledge base.

As mentioned previously, the EvoRoom curriculum included activities across a number of different contexts, including at home, at school in the students' regular classroom, at school in the smart classroom, and at the zoo, on a field trip. After conducting inquiry activities in the class, and during homework, students were engaged in a smart classroom activity (i.e., where they were engaged as a group in the "EvoRoom" itself). The interactions within the EvoRoom were carefully designed to explore research questions related to large, immersive environments (Lui & Slotta, 2012). The walls of the room were rendered as large animated simulations of the rainforest at 8 different historical time periods (200, 150, 100, 50, 25, 10, 5 and 2 million years ago). The teacher coordinated students' investigation of the evolution of the rainforest, as they made use of carefully designed tablet computers to add observations and reflections. A trip to the zoo is used to promote reflections about biodiversity and habitat, followed by another visit to the EvoRoom where students investigate the biodiversity of the present day rainforest, set in various human- and nature-impacted contexts (e.g., from climate change). Further details of the design are provided in the design analysis section.

The school itself was located within a large and ethnically diverse urban setting. The participants for the current iteration consisted of two sections of Grade 11 Biology (n=56). For the majority of the activities, students were divided into groups of 3-4, with different groupings for different activities. It should be noted that, although there were significant changes between each design iteration, and the KCI model served as an important referent and guide for design decisions, none of the designs were explicitly connected to the role of epistemic cognition within KCI. While such elements are clearly essential to the model, they were not at the forefront of concern for researchers, who were focused on activity sequences, as well as specific questions about the smart classroom (Lui & Slotta, 2012). The present research examines the role of epistemic cognition within the EvoRoom designs, performing an MBDR analysis that will serve to strengthen the coherence of the KCI model in terms of its epistemic commitments.

4. Data Analysis

4.1 Design Analysis

The first stage of the MBDR analysis entails mapping the epistemic commitments (EC) of the KCI model onto the EvoRoom curriculum design. Figure 2 connects the five epistemic commitments of KCI to the various components of the EvoRoom curriculum design timeline. As shown, the design of EvoRoom curriculum did address the major epistemic commitments of KCI. However, it notably did not make any explicit attempts to address students' epistemic cognition, such as through reflections or discussions about the purpose of learning, the goals of the curriculum, etc. Nor did the specified activities include details about the role of epistemic cognition in the inquiry learning (Chinn et al, 2011).

4.2 Enactment Analysis

The second step of the MBDR analysis is to evaluate whether the EvoRoom curriculum was enacted faithfully to the design (see Figure 3). Enactment data included the following:

1. Digital learning artifacts, including posts to the online learning portfolio, contributions to the EvoRoom database throughout the Evolution Activity, and evidence/claims collected using Zydeco (for both the Zoo Field Trip and Biodiversity Activity) (n=56);
2. Pre/post summative rating scale instruments and that were completed before and after the entire 10-week curriculum unit (n=56), as well as before and after the Zoo field trip (n=112);
3. Open-ended survey items completed near the beginning and end of the 10-week curriculum unit (n=56);
4. Student interviews, completed after the final EvoRoom biodiversity activity (n=4)
5. Researcher field notes for the EvoRoom Evolution Activity, Zoo Field Trip and Biodiversity Activity

5. Discussion

The enacted EvoRoom design provides feedback that may be used to help strengthen the epistemic elements of future design iterations. It also provides insights as to how the epistemic commitments of the KCI model can be improved. One area of feedback into the design is concerned with the semantic organization of the knowledge base. Throughout the EvoRoom curriculum, the ability to search for and retrieve specific artifacts from the knowledge base was limited by the quality of student tagging. Within the smart classroom activities, this issue was less pronounced because there were only 12-16 students contributing to the knowledge base at a time. Here, the teacher was able to circulate the room and remind students to tag data, and the persistent aggregate display in the provided additional visual evidence showing if/when tags were appropriately applied. However, during the Zoo field trip, there was a much larger cohort of students who were simultaneously contributing to the knowledge base (n=112). Due to time constraints, many students chose to collect various multimodal artifacts as evidence and then tag them later (if at all), or otherwise poorly tagged them in haste. This meant that a large quantity of evidence remained unsearchable and unused.

Figure 2: Analysis of how the epistemic elements of KCI appeared within the EvoRoom curriculum design

EvoRoom Curriculum Design:

Time →

KCI Model: Epistemic Commitments	**Online Learning Portfolio (ongoing)**	**EvoRoom Evolution Activity (Week 2)**	**Zoo Field Trip (Week 8)**	**EvoRoom Biodiversity Activity (Week 10)**
Epistemic Aims and Value Students identify as a knowledge community with the shared goal of learning together, advancing the community's knowledge, and developing shared ideas and understandings about the targeted science learning expectations	Students identify as a knowledge community with the shared goal of learning together, advancing the community's knowledge, and developing shared ideas and understandings about the targeted science learning expectations			
Structure of Knowledge The structure and organization of knowledge within the knowledge base are emergent, based on student-contributed content; 'progress' is made visible	Individual blog posts with peer comments; Collaborative wiki pages; scaffolded titles	Co-constructed aggregate cladogram, based on real-time observations	Shared, multimodal evidence base with folksonomic tagging structure	Shared, multimodal evidence base with location-based tags
Sources of Knowledge, Justification and Epistemic Stance Sources: knowledge base is understood as "their community resource"; teacher is regarded as an expert collaborator Justification: *gap in model* Epistemic Stance: *gap in model*	Sources: authoritative sources; Justification & Epistemic Stance = gap in model	Sources: primary observations, peers; Justification & Epistemic Stance = gap in model	Sources: primary observations, peers; Justification & Epistemic Stance: Zydeco CER	Sources: primary observations, peers; Justification & Epistemic Stance: Zydeco CER
Epistemic Virtues and Vices Virtues: knowledge community membership, sharing of ideas, (also implicit are shared social conventions and practices, discourse "rules") Vices: (implicit are 'knowledge hoarding,' competitiveness, valuing individual achievement over collective advancement)	Virtues: meaningful contributions to the shared knowledge bases for each activity; justificatory rigor (i.e. no satisficing throughout knowledge negotiations); prioritizing collective advancement over individual. Vices: lack of contributions to the knowledge base; frequent satisficing of group decisions/knowledge claims, and maintaining a competitive, grades-first mentality throughout the activities			
Reliable Processes Knowledge-building processes; constructivist inquiry activities; discourse; practice/application; reflection	Knowledge-building processes; constructivist inquiry activities; discourse; practice/application; reflection			

One area of theoretical insight that would feed into the KCI model would be the inclusion of epistemic "virtues and vices" (Chinn et al, 2011) for collaborative inquiry. An epistemic virtue is something that is helpful in the achievement of epistemic aims - for example, the establishment of a knowledge community and the subsequent learning that occurs as a result of community membership. Conversely, an epistemic vice is something that impedes, rather than facilitates, the attainment of these epistemic aims. Throughout the EvoRoom curriculum, students recognized the value of the shared knowledge base in facilitating their learning. However the establishment of a true knowledge community was hindered by two particular epistemic vices; namely, the perceived absence of shared goals, as well as their individual (i.e. competitive) summative evaluations.

Figure 3: The enactment analysis revealed how the designed EC were manifested in the enacted curriculum

Enactment Analysis Findings

Online Learning Portfolio (ongoing)	EvoRoom Evolution Activity (Week 2)	Zoo Field Trip (Week 8)	EvoRoom Biodiversity Activity (Week 10)

Epistemic Aims & Values

- According to an open-ended post-survey, (n=40), the majority of students (67%) perceived the EvoRoom activities as having a greater emphasis on collective knowledge advancement rather than individual learning gains.
- Students identified shared goals within all four EvoRoom curriculum activities. However, students felt that shared goals were most prominent in the Zydeco Zoo activity and the Biodiversity Activity.
- The majority of students (83%) felt that their own contributions to the shared knowledge base were helpful to the learning of others.
- A pre/post likert questionnaire administered before and after the Zoo field trip revealed that students who participated in the EvoRoom curriculum showed a significant improvement in their perceived knowledge communities (t=-2.684, df=37, p-value=0.01081) compared to students who did not participate in the EvoRoom curriculum (t=0.6114, df=26, p-value=0.5463)

Structure of Knowledge:

Online Learning Portfolio (ongoing)	EvoRoom Evolution Activity (Week 2)	Zoo Field Trip (Week 8)	EvoRoom Biodiversity Activity (Week 10)
The level of completion of the Borneo Field Guide assignment (86%) was higher than the level of completion for the Borneo Timeline wiki pages (47%) and the Timeline Summary (12%).	Two sessions completed the activity pencil and paper rather than the tablet app. Within the paper sessions, the higher-order reasoning question (question 3) was left blank by 70% of respondents. Students who used tablets worked collaboratively and were able to share their knowledge artifacts with each other such that none of their responses were left blank.	Of the 655 pieces of data that were collected, the majority consisted of photos (79%) or the combination of photos with text (10%). The remaining 11% of data used audio (1%), video (3%), text (4%), or a mix of media types (3%). 67% of data artifacts contained at least one folksonomic tag, while 33% remained untagged.	The tagging structure of data artifacts was taxonomic rather than folksonomic. Here, a much higher proportion of evidence was used to support knowledge claims throughout the biodiversity activity (42%) compared to the Zoo field trip activity (15%).

Sources of Knowledge, Justification, and Epistemic Stance:

- A pre/post open-ended survey was administered to students before and after the EvoRoom curriculum (n=40). Pre-survey results indicate a heavy reliance on authoritative sources of knowledge (89%), whereas post-survey results show a more even distribution between authority (33%), peers (28%) and the self (38%) as sources of knowledge.
- Justification of knowledge was weakest in the Online Learning Portfolio and in the EvoRoom Evolution Activity, where knowledge contributions were mostly factual and required little negotiation. Justification of knowledge was strongest in the Zydeco Zoo field trip activity because scaffolds to support the justification of knowledge were built into the design of the Zydeco app. Although the Biodiversity activity also used Zydeco, there was evidence of students satisficing their epistemic stance in favour of consensus/agreement within the group (e.g. using approaches such as a 'group vote' rather than argumentation/justification of knowledge claims)

Epistemic Virtues and Vices:

- Most students participated fully in all activities and contributed their findings to the shared knowledge base
- There was some evidence of satisficing throughout the Biodiversity Activity, therefore evaluating this epistemic vice requires further evaluation in subsequent designs once the "Justification" and "Epistemic Stance" dimensions have been refined
- Students recognized the EvoRoom Curriculum as focusing on collective advancement rather than individual gains

Reliable Processes:

- The achievement of the epistemic aims can be used as an indicator that the underlying learning processes were, in fact, reliable.
- Students were also given an open-ended post-survey in which they were asked how much of the EvoRoom curriculum they were likely to remember next year in comparison to the other units of the course. The majority of students (62%) indicated they would remember more, citing reasons such as 'active learning,' 'application' and 'understanding' (rather than memorization). 17% indicated they would remember less, primarily due to interest in other topics, or preference to learn/study independently rather than with classmates.

6. Conclusion

MBDR can be used as an evaluative tool to identify when, where, why and how a particular design is achieving or failing to achieve its curricular aims. This paper examines how the epistemic commitments of the KCI model were mapped onto the design of the EvoRoom curriculum, and – subsequently – how those commitments played out in the enactment of the curriculum. While the EvoRoom curriculum wasn't designed with epistemic cognition explicitly in mind, it provides an interesting opportunity to take an 'epistemological pass' at the design, in order to inform future design iterations. MBDR could be used to evaluate other aspects of the design as well, including technological elements or pedagogical affordances. Similarly, different curricula could be designed, enacted and evaluated using the same model as its basis. The enacted designs are valuable for both informing future design iterations, as well as generating theoretical insights that could contribute to the refinement of the model itself.

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