Divergent inquiry for exploratory learning: A multimodal perspective

Abstract

Traditionally, research into effective collaboration has focused on learners achieving "convergent conceptual change", in which learners move towards shared understandings and goals. However, there is a growing spectrum of educational designs, especially within computer science and engineering education, in which learners are encouraged to engage in divergent forms or inquiry and exploration, while still engaging in effective collaboration. This paper introduces the notion of divergent inquiry – inquiry in which learners are encouraged to develop their own problem states and goals that differ from their peers – and an approach for recognizing effective collaboration, even when convergent conceptual change does not happen. Using a museum exhibit at a large urban science center, we show how the ability to see and interact with the work of others can provide unique opportunities for learners to engage in productive collaboration, even while pursuing divergent goals.

Introduction

Inquiry research in science education typically takes a "convergent conceptual change" perspective on student learning and collaboration (Roschelle, 1992; Roschelle & Teasley, 1995), in which learners work together to come to common understandings. However, in computer science and engineering education, where tinkering and exploration are more common (Martinez & Stager, 2004; Perkins et al., 1986), divergent inquiry - inquiry in which students are encouraged to develop their own problem states and goals that differ from their peers - has real, unique benefits. It therefore becomes important, when designing technology-enhanced learning environments for creative environments, to understand and consider the benefits that divergent inquiry can provide for productive collaborative learning. The goal of this paper is to advance the claim that divergent inquiry holds different benefits from convergent inquiry. In the sections below, we further define the unique characteristics and pedagogical needs for divergent inquiry, and give an example of how divergent inquiry has been successfully implemented to support effective learning and collaboration.

Methodology

Research Setting

In order to understand how divergent inquiry can play out in a naturalistic setting, we focused our analysis on *Oztoc* - an interactive tabletop exhibit at a large urban science museum situated in a multicultural metropolis (see Authors, 2015a). In *Oztoc*, visitors design and build electrical circuits (which act as glowing fish lures) to attract and catalog bioluminescent creatures swimming in a pond (see Figure 1). *Oztoc's* narrative gives learners a situated context in which to engage in engineering practices such as tinkering, exploration, and problematization, while providing visitors some freedom in choosing their own goals (e.g., which types of fish to target and circuits to build) while still giving them a common set of materials and processes.

Figure 1. Players assemble virtual circuits using wooden blocks that represent resistors (1), batteries (2), timers (3), and different colored LEDs (4). Participants make connections (depicted as lines on the tabletop - 5) by bringing the positive and negative terminals of the blocks (displayed by the table) in contact with one another. Creating a successful circuit causes the LEDs to glow and lures fish attracted to that light.

Data sources and analysis

In order to support the validity of divergent inquiry, we will build on several earlier studies into visitor exploration, collaboration, and learning at the Oztoc exhibit. Building on analyses from earlier studies (Authors, 2014, 2015a, 2015b, *in review*), we focus here on how the interactions described below support our stance on the need to attend to the unique affordances of divergent inquiry. In the studies discussed below, we blend of multimodal qualitative, quantitative, and learning analytics approaches to show that visitors were able to achieve more complex and varied goals by working together despite having different individual goals.

Findings

Building on the ideas of others: Echoes

Analysis of users exploration in *Oztoc* introduced the concept of echoes – the building off of some sub-element of a specific, technical work of another in context - and how echoes specifically supported visitors in using the tinkering of others to develop their own divergent goals (Authors, *in review*). An important aspect of echoes is that they work of peers is visible and inspectable. Tabletops have been shown to be particularly effective at supporting this kind of shared observation (Authors, 2015a). We (*in review*) used a relationship mining approach (Baker & Siemens, 2014) to look at 8243 circuits made across 329 visitors we found that echoing the work of others was significantly correlated with building a working circuit (0.6724, $p<0.001$). In contrast, other factors (such as the number of people at the table) had no significant effect. Of particular interest to us was that when visitors got stuck they would use the work of others to help them progress or to understand their own exploration.

Recognizing divergent inquiry within and across groups

We were then curious how this visibility of other's work was being used - in particular, were visitors simply following the work of others or were they using the work of others to develop their own goals and exploratory pathways? To understand what was happening during these moments, we coded and analyzed selected collaborative interactions between visitors simultaneously engaged at the tabletop (Cohen's Kappa = 0.93). While in some cases visitors did simply work together, in many cases they moved seamlessly between shared and divergent goals (Authors, 2016). In the exchange below (Table 1), the mom articulates a different goal state than the one proposed by her son (i.e., accumulating points). The son further advances his own divergent goals by deciding to explore what happens when he adds more batteries to his circuit. In the end both the mom and the son ended up making a variety of circuits, providing feedback to each other in the process, all while following their own avenues for inquiry.

Table 1: Within group divergent collaboration. Despite "working together" at the exhibit each family member advances their own divergent inquiry question, while still being able to build off and learn from the exploration of the group

Son:	I have 10, got 10 [points]!
Mom:	Come thing come back over to me…
Dad:	You have no points.
Son:	Yeah, you have no points mom.
Dad:	That's cool!
Mom:	I don't need points.
Son:	What happens if you have two batteries?
Dad:	I got one!
Son:	What happens when you have two batteries?
Son:	I want to see what happens when you have two batteries.

Open-ended, exploratory inquiry activities can also differ from many traditional learning activities in that they do not always require clearly defined endpoints. The openness for participants to enter and leave the activity at different times sets the stage for individual participants to have different levels of knowledge about the domain. In *Oztoc*, for instance, a participant who has been at the exhibit longer may have a deeper understanding of the underlying mechanics than a newcomer. This sets the stage for productive mentoring or collaboration, even though the participants may have divergent inquiry goals. In Table 2, the man had been playing with *Oztoc* for several minutes before another family arrives. Seeing what the family is doing, and building on his own understandings, he works with the family to reconceptualize the problem space. The ability of the man to work with the family highlights the unique affordances of open-ended environments to support independent inquiry, while still providing opportunities for productive collaboration.

Table 2: Cross group divergent collaboration. The man is working on a different problem at the table, but because he can see the other group's struggles he is able to intercede and collaborate with them to help then figure out a new path for investigation

Man:	The other trick is if you want a bigger fish put the same color LEDs.
Woman:	Ok
Man:	A bigger fish, because it attracts a bigger.
Woman:	Ok
Man:	So if you've got two reds you'll get two times the size.
Woman:	Ok, you saw that [her son]?
Man:	So just replace one of your LEDs with the same color.
Man:	Right the same color
Man:	So you'll get twice the size fish

Conclusions and Significance of Research

The examples above serve as an existence proof of the need to seriously consider divergent inquiry as a valid pedagogical approach to technology-enhanced learning designs. Developing divergent inquiry activities requires thinking hard about whether you are supporting a "learning goal" (such as "everybody becomes familiar with structure of cell") or a "learning process" (people need to get to the point where they can build something in Python but whatever they intend to learn is irrelevant). If the goal of the activity is learning *how to learn*, then curricula in which there is no clearly defined "optimal" outcome, in many cases, may be preferable. As the professional workforce moves increasingly towards interdisciplinary and distributed collaborations, predicated on creative knowledge work, there's a need to support students in learning how to think in more open-ended and exploratory ways. We believe that developing an understanding of how to support open-ended and exploratory learning environments has broad applications. In makerspaces, for example, while learners often pursue their own projects and goals within a similar domain (e.g., building circuits and writing Arduino code), there are ample opportunities for learners to share their expertise with their peers (e.g., sharing snippets of code or circuit diagrams).. Understanding the ways in which learners can learn from, and collaborate, with others while pursuing divergent goals opens up new ways to best support and evaluate the learning taking place.

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