Generative Conversations in Game-based Learning

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Abstract: This study examines a secondary level game-based learning curriculum centered on a multi-player 3D game, in which students collaboratively make sense of phenomena related to the behavior of charged particles in electric and magnetic fields. We study the interaction among the students while they enlist resources in the form of the game and curriculum materials that serve as scaffolds for sense-making. Through the consideration of coordination of the perception-conception of resources with actions related to scientific inquiry processes, potential sites for generative conversations were identified. We suggest future directions for the design and study of game-based learning curriculum to foster generative conversations that better shape students' sense-making trajectories.

Introduction

Inquiry has come to be the object of good science education and its use as a teaching and learning approach has been the focus of research and discussion on educational reform (Anderson, 2002). In addition, changes that have taken place over the past few decades in the conceptualization of science and learning necessitate the need to adopt pedagogical approaches that allow students to engage in dialogical discourse processes consistent with the view of science as a practice with social and epistemological dimensions (Grandy & Duschl, 2007).

In order for learners to gain a deeper understanding of a body of science knowledge and the practice of science, it is vital for them to be engaged in *doing science*, in the practices and methods related to science-in-the-making used by scientists instead of just focusing on *learning about science*, that is just learning the established results of science (Van Joolingen, de Jong, & Dimitrakopoulou, 2007). Lemke (1990) likens the practices and methods used by scientists to "talking science" or "doing science through the medium of language" (p. ix) which entails participating in a whole spectrum of activities ranging from observation to the formation of generalizations using language as a system of resources for meaning-making. Meaning-making has also been positioned as a dialogic process employing a scientific social language (Mortimer & Scott, 2003). For Suthers (2006), meaning-making, in particular intersubjective meaning-making, is evidenced when participants involved in a collaborative learning activity contribute to a "joint composition of interpretations" (p. 321) which entails examining the interactions among participants while they engage in the activity.

Technology has shaped much of the developments taking place in the design of learning environments and offers possibilities for the provision of rich contexts within which meaning-making may be situated. Online role-playing games have grown in popularity in recent years (Galarneau & Zibit, 2007) and educators, academics and researchers have discussed the potential offered by 3D game environments to foster deep learning (Gee, 2003; Squire & Jenkins, 2003). For example, 3D game environments can be designed to involve the learner as an active participant in situations that may not be accessible in a traditional classroom (Jones & Bronack, 2007). During game-play, the player is constantly involved in a cycle of questioning and the formation, testing and revision of hypotheses; processes that happen rapidly and frequently during the game and accompanied with immediate feedback (Van Eck, 2007). Hence, 3D game environments lend themselves naturally to the provision of dynamic contexts within which learners may test scientific conjectures. This is especially valuable in the domains that deal with abstract concepts and phenomena for which many learners face significant difficulties understanding (Squire, Barnett, Grant, & Higginbotham, 2004). 3D game environments can also immerse learners in simulated worlds within which they may explore and make sense of the scientific phenomena instantiated in such worlds, hence facilitating their active participation and situated understandings (Steinkuehler & Duncan, 2008).

Situated learning is concerned with how learners dynamically construct knowledge and how the process is shaped by the ways in which they conceive of their circumstances, interact with one another, and act as members of a community (Clancey, 1995). Compared to simulations, games allow learners to be immersed in an environment where they are able to interact with the game as a system instead of as a combination of unrelated events, hence fostering the development of an "embodied empathy for a complex system" arising from the player being simultaneously inside the game as an avatar interacting with the game-world as well as outside the system as the one controlling the avatar (Gee, 2005, p. 82). Helping learners to achieve an embodied understanding for scientific phenomena by way of being embedded in a dynamic game system where they learn through experience and active experimentation (Chee, 2007) is what the *Centauri Learning Program*, a Physics learning program sets out to achieve. It employs the use of a 3D game environment to engage secondary school students in inquiry practices related to the sense-making of scientific phenomena that are unfamiliar to them. These inquiry practices include the making of observations, testing of hypotheses, engaging in formulation of explanations based on evidence, and the communication and justification of explanations (Grandy & Duschl, 2007).

In order for abstract and oftentimes, invisible, phenomena to form the focus of a learner's inquiry within a 3D game environment, the phenomena first has to be rendered visible for observation and subsequent manipulation through some means of representations within the game. The sense-making process is not one that is straightforward, especially when an unfamiliar phenomenon is being presented to the learner, consistent with the science-in-the-making situations that scientists encounter. This is further complicated by the fact that what information a learner conceives as evidence in a hypothesis-testing process is influenced by what the learner perceives to be of significance in the information in the first place. How the learner perceives a representation is tightly coupled to the meaning the learner attaches to the representation; the *perception* of the representation (i.e. how the representation is viewed) and the *conception* of the representation (i.e. how the representation is understood) mutually affect one another simultaneously (Clancey, 1997). This "dynamic simultaneity in (the) coupling of perception and conception" (ibid, p. 213) implies that what an observer perceives depends on how the observer interacts with the things in the world and what is being attended to as an object of interest. Clancey (2005) demonstrated an example of this dynamic simultaneity in his study of the interaction between two students as they learnt about linear equations using a mathematics software and he examined how the "process of 'viewing as' and interpreting is inseparable in human experience, so seeing something as meaningful and conceiving what it means occur together and is only subsequently followed by a coherent linguistic statement by which the meaning is represented" (p. 114).

In addition to the tight coupling between perception and conception of information, one also needs to consider the coordination between the perception of information and action because what one sees and does arise simultaneously giving rise to a new coordination of perception and action that shape subsequent behavior (Clancey, 1995). In this paper, we examine interactions among students involved in the *Centauri Learning Program* as they collaboratively engage in scientific inquiry processes while enlisting resources in the learning environment (the game and the associated curriculum materials that act as scaffolds). In particular, we study how the coordination between their perception-conception of scenarios encountered and their actions shape their sense-making trajectories.

The Centauri Learning Program

The *Centauri Learning Program* consists of a game-based curriculum designed around the use of a multi-player 3D game entitled *Escape from Centauri 7* (EC7) to support the learning and application of Physics concepts and principles to make sense of particle dynamics in electric and magnetic fields. EC7 (see Figure 1) is modeled upon puzzle games where players solve puzzles of increasingly complex natures with each successive mission or level. Players take on the role of explorers who crash-land on a planet where they encounter alien technology, such as emitters that emit charged particles. Players need to direct the charged particles at a target – a generator that in turn powers the next emitter, and so on. The aim is to reach the final mission where they direct charged particles towards generators that power-up a giant coil-gun that will propel a distress signal into space to enable them to escape from the deserted planet.

Figure 1. Screenshots of the main navigation map showing the levels (left) and the interface (right).

In order to manipulate the motion of the particles, players need to position vehicles, which deploy fields, in the paths of the particles. Players need to decide on the type of field to use (whether uniform electric or uniform magnetic), the position of the vehicle with respect to the particles and the setting of controls that determine the strength and direction of the field. A mission is complete when players manage to guide the charged particles around obstacles to hit the final target in the mission. The game-play would be straightforward if not for the fact that players are not told which field is of which type; part of the challenge is to make sense of the nature of the unknown fields through experimentation. Players are not assumed to have any prior knowledge of the nature of the fields; instead they need to make use of their understanding of Newtonian Physics to deduce how the fields affect particle behavior in order to complete missions strategically and without sole reliance on trial-and-error methods.

The interaction of charged particles with electric and magnetic fields is not one which is directly perceived with one's senses in everyday experience; it is an abstract phenomenon due largely in part to the invisibility of fields. EC7 depicts a sci-fi world in which charged particles, fields and the effects of their interactions are made visible and can be viewed from different perspectives in a free-roaming camera mode. As such, it allows the learner to dynamically manipulate the trajectories of charged particles through the adjustment of field variables. In the process, learners actively make sense of how charged particles behave in electric and magnetic fields through self-directed meaning-making processes grounded in embodied cognition where knowledge is seen as a capacity for action rather than as an object that can be transmitted from teacher to learner (Chee, 2007).

Providing the game experience alone does not necessarily ensure that deep learning will take place. In fact, it was one of our concerns that learners might go through the game, successfully completing missions through trial-and-error but without understanding the Physics concepts and principles underlying the behavior of charged particles in fields. This underscores the importance of designing the game-based learning experience by providing guidance and scaffolds so that learners will have opportunities to partake in the "socially shared practices of science" related to questioning, data collection, description of observations, finding patterns in observations and data and the development of scientific reasoning (Enfield, Smith, & Grueber, 2007). With this in mind, a curriculum was designed around EC7 to enable students to make sense of phenomena that were unfamiliar to them through participation in scientific practices. The curriculum was targeted at students in the third year of their secondary school year (ages 14-15 years) and who had not been taught about the interactions of charged particles with uniform electric and magnetic fields. It focused on fostering practices related to theory building (e.g. finding patterns in observations, and the forming, testing and revision of hypotheses) where students make sense of phenomena that are new and unknown to them. To scaffold the sense-making process, activity cycles comprising *game-play*, *small-group discussions*, and *whole-class forums* were employed to orchestrate the game-based learning experience.

The activity cycles are based upon the conception by Rogoff (1997) that the development of learners entails their participation in sociocultural activities that involve personal, interpersonal as well as community processes. Students work in teams of three to complete game missions and make sense of the behavior of the charged particles in the fields during game-play. During *game-play*, they actively experiment with electric and magnetic fields to control the motion of the charged particles and in the process gain a first-hand embodied sense of how fields and particles interact. As they engage in *small-group discussions*, they articulate their thoughts in the process of negotiating meaning with fellow team-members before converging on generalizations which they then subject to further interrogation by other teams during *whole-class forums*.

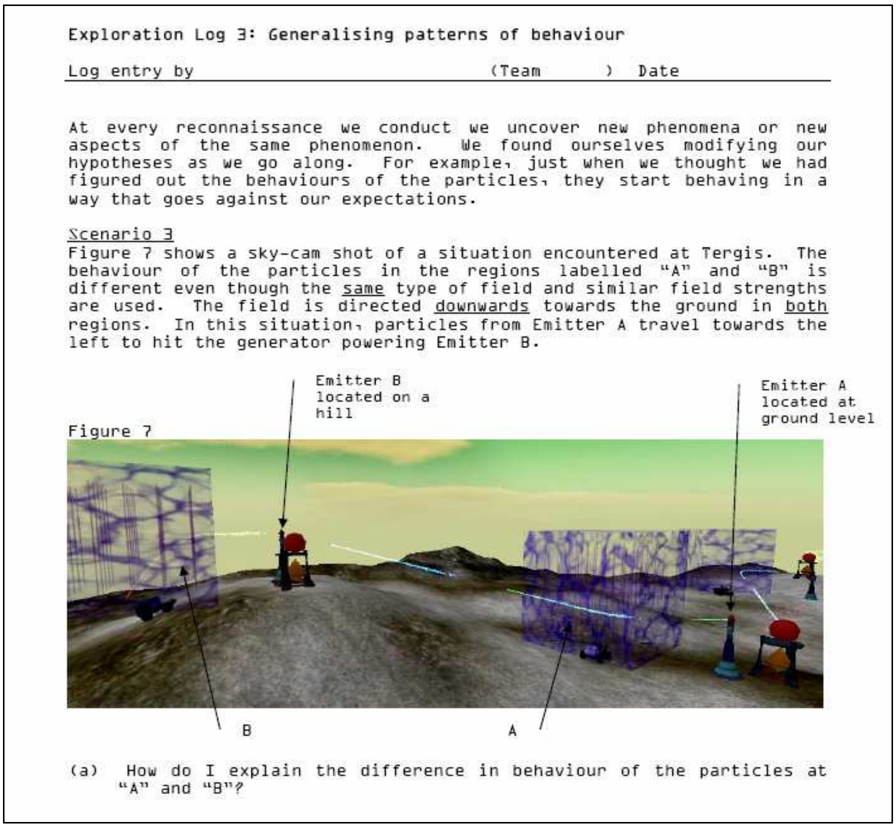
The *Centauri Learning Program* comprises a total of four activity cycles. Each activity cycle starts with game-play where students play one or two levels of EC7. Students are provided with an Exploration Log (log) that scaffolds their sense-making of the phenomena through the provision of scenarios and discussion questions that serve to draw their attention to various aspects of the phenomena. Each log is designed to scaffold students' sense-making through a dialogic process employing a scientific social language that is characterized by description, explanation and generalization (Mortimer & Scott, 2003). Description entails the making of statements providing an account of the phenomena in terms of its constituents; such statements often form the basis for evidences that need to be cited in explanations. Explanation involves accounting for the phenomena by establishing relationships between the phenomena and concepts through the application of some form of model. Generalization involves the making of a description or explanation that expresses a "general property of scientific entities, matter or classes of phenomena" (Mortimer & Scott, 2003, p. 32).

The level design of EC7 is closely aligned with the focus for each activity cycle; new physical phenomena or different aspects of the same class of phenomena are introduced at various missions to perturb the students' conceptions. Table 1 summarizes the key focus of each activity cycle and illustrates how the elements in EC7 and the accompanying Exploration Log for each activity cycle are designed such that the sense-making taking place in one cycle may build on what had taken place in previous cycles. For example, during Cycles 1 and 2, students go through the process of investigating the effect of the uniform electric fields on positively charged particles. During Cycle 3, the students encounter a new type of particle that behaves differently from what they have already experienced in previous cycles. This scenario sets the context for the students as they examine the reasons underlying the difference in behavior.

Table 1: Key focus of each activity cycle

Activity Cycle	Key Focus
Cycle 1 with sense-making scaffolded by Exploration Log 1	Phenomena related to charged particles (represented as orange-colored particles) traveling parallel or anti-parallel to a uniform electric field – acceleration and deceleration of particles
Cycle 2 with sense-making scaffolded by Exploration Log 2	Phenomena related to charged particles (learners were informed through a clue in the log that the orange-colored particles are positively charged particles) traveling in a uniform electric field – formation of parabolic paths
Cycle 3 with sense-making scaffolded by Exploration Log 3	Phenomena related to positively and negatively charged particles (introduced at the mission played during this cycle and represented as blue-colored particles; learners were not informed that these are negatively charged particles) traveling in a uniform electric field
Cycle 4 with sense-making scaffolded by Exploration Log 4	Phenomena related to positive and negative particles traveling in a uniform magnetic field – formation of circular or helical paths, depending on the angle between a particle's initial velocity and field direction

The logs are positioned as journals with entries made by explorers on their observations, explanations, and generalizations (Mortimer & Scott, 2003) as they explore the interaction between the particles and the fields. Each activity cycle are anchored upon the log that provides one or more trigger scenarios accompanied by guiding questions to scaffold students' formulation and testing of hypotheses in order to make sense of the interaction between the charged particles and the fields. As an example, Figure 2 shows an excerpt from the log used in Activity Cycle 3.


Exploration Log 3: Generalising patterns of behaviour

Log entry by (Team) Date

At every reconnaissance we conduct we uncover new phenomena or new aspects of the same phenomenon. We found ourselves modifying our hypotheses as we go along. For example, just when we thought we had figured out the behaviours of the particles, they start behaving in a way that goes against our expectations.

Scenario 3

Figure 7 shows a sky-cam shot of a situation encountered at Tergis. The behaviour of the particles in the regions labelled "A" and "B" is different even though the same type of field and similar field strengths are used. The field is directed downwards towards the ground in both regions. In this situation, particles from Emitter A travel towards the left to hit the generator powering Emitter B.

(a) How do I explain the difference in behaviour of the particles at "A" and "B"?

Figure 2. A scenario presented in the Exploration Log used during Activity Cycle 3.

Research

This study is a design-based research embodying conjectures (Sandoval, 2004) that a deeper understanding of Physics and of scientific inquiry practices may be fostered through a game-based learning approach where students jointly investigate and make sense of unfamiliar phenomena in a simulated world. We are interested in studying how the sense-making process unfolds as the students collaboratively study the phenomena while drawing upon material resources in the form of the game and the logs. At the time of writing, the research had gone through four iterations. In the following sections, we provide a brief overview of the participants involved in the third iteration of the design-based research, the method of data collection, and data analysis.

Participants

The *Centauri Learning Program* was implemented as a module comprising eight sessions with each session lasting 1 hr 30 min in an independent, all boys' school. The school set aside a period of three weeks during which the school time-table was suspended to allow their secondary three students (ages 14-15 years) to attend 12-hour modules covering a range of subjects and topics. A total of 36 students volunteered to participate in the *Centauri Learning Program* module. We worked with a Physics teacher, Mr. Teo (names used in this paper are pseudonyms) who had observed the conduct of the module with a different group of students at an earlier iteration. During the third iteration of the research, Mr. Teo facilitated the module as the main teacher with the first author supporting as co-teacher by providing just-in-time facilitation during small-group discussions among the students. Mr. Teo was provided with a facilitation guide comprising all lesson plans and curriculum materials. Regular discussions were held between Mr. Teo and the first author throughout the module. In addition, two LSL colleagues were present during a number of the sessions to record field notes and to conduct in-situ interviews.

Data Collection

During the sessions, students worked in groups of three which they formed on their own. Four student groups were video-recorded and the remaining eight groups were audio-recorded. Artifacts such as the students' completed logs, presentation charts used during whole-class forums, final products encapsulating their generalizations of the phenomena, and reflections individually penned by the students were collected. Pre- and post-intervention interviews and focus group discussions with the students were audio-recorded or video-recorded. Field notes were taken during the sessions and the discussions with Mr. Teo after each session were audio-recorded as well.

Pre- and post-tests were also administered. The instrument comprised of eight multiple-choice questions drawn and adapted from the Force Concept Inventory (Hestenes, Wells, & Swackhammar, 1992; Halloun, Hake, Mosca, & Hestenes, 2008), which was designed such that respondents need to make a choice between Newtonian concepts and commonsense beliefs or misconceptions. The Inventory probed for misconceptions as the distracters for each question were based on research findings about students' commonsense beliefs. A second tier was added to the multiple-choice questions by way of asking respondents to provide justifications for their choice. In addition, three short-answer questions were added such that the pre- and post-test would address the range of Physics concepts and principles fundamental to the content of the *Centauri Learning Program*. Taken as a whole, the pre- and post-tests were designed to provide an indication of the students' understanding of the concepts related to Newtonian Physics and to the dynamics of charged particles in fields.

Data Analysis

The *Centauri Learning Program* adopts the situated view towards learning that emphasizes development of knowledge in the course of activity as learners participate in collaborative processes (Clancey, 1995). As Interaction Analysis views knowledge and practice as being "situated in the interactions among members of a particular community engaged with the material world" (Jordan & Henderson, 1995, p. 41), it lends itself well as a method for analysis of the video data collected in this study. Interaction Analysis, a video-based analysis, is characterized by the investigation of "human activities such as talk, nonverbal interaction, and the use of artifacts and technologies, identifying routine practices and problems with the resources for their solution" (ibid, p. 39). As part of the process to study the interactions among students as they played the game and participated in discussions, content logs were made while the video data were viewed. The content logs summarized events observed while viewing the video data collected for the four student groups being studied. Hence they served as an overview of the data collected as well as a record of group interactions that were later discussed in context of the research focus. The logs also record interesting segments or interactional "hot-spots" (ibid, p. 43) where more detailed transcriptions could be made for in-depth study. One interactional "hot-spot", signaled by an increase in discussion activity among students, was observed across all iterations and it coincided with the start of Activity Cycle 3 when students first encountered the negatively charged particles represented as blue-colored particles in the game. In the following section, we describe the analysis of the interactions that took place among a group of students as they attempted to coordinate their perception-conception and action (Clancey, 2005) in order to make sense of the situations encountered in the game and in the scenario presented in the accompanying Exploration Log. A paired *t*-test on the pre- and post-test scores was conducted to gauge the students' conceptual understanding of the behavior of charged particles in electric and magnetic fields.

Analysis of the Interactions

The paired *t*-test conducted on the pre- and post-test scores revealed a significant difference between the scores ($t(33)=11.9$, $p<0.00$) and suggested that there were learning gains on the whole with regard to students' understanding of the concepts involved. For a qualitative study of how the students made sense of unfamiliar phenomena, we examined the interactions among the students as they engaged in game-play and discussion.

During Activity Cycles 1 and 2, the students encountered positively charged particles during game-play and had already formed certain relations pertaining to the behavior of positively charged particles in the electric field. This formed the backdrop to the episode that took place at the beginning of Activity Cycle 3 when three students, Peter (P), James (J) and Billy (B) attempted to answer a question posed in a scenario in the log (see Figure 2) – why particles showed different behaviors while traveling in two regions (region A and region B) even though the fields in both the regions were the same type of field with the same direction and strength. Three excerpts containing discourse related to the question in the scenario will be presented. The first excerpt began at the point when P was studying the scenario in the log while waiting for the game mission to load.

P: If both are directed downwards, how come this one goes left? (P asks J, pointing at his own log.)
J: (J takes the log from P.) Huh? Both are directed downwards?
P: (Points to the log and reads from it.) "The field is directed downwards in both regions."
J: Same type of field?
P: (Points to a phrase on the log and reads it.) "Same type of field and similar field strengths".
J: (Pauses to read the log.)
P: (P tries to take his log back from J.) Never mind, I think we go to the game and see first.
J: (J pulls the log back from P.) No, this is not (J points to the log). I think from the top, it's just move up. This one . . . both directed downwards?
P: (Silently points to the specific phrase in the log to J.)
J: Huh? Then this is a different field (points to the diagram). Confirmed.
P: No, but they say it's the same field. (Looks at the log.) It's the same type of field of similar field strength and it's directed downwards in both regions.
J: (Gives a quizzical look.) Why so strange?
P: We need to play this.
J: (J starts to play the game; B leans closer over to look.) Hey? Blue trail. Oh, it's a blue one. Let's see what can my field do. (Adjusts controls for the field strength.) Hey, it travels opposite, you know. I push here (points to the screen and moves his finger to the left), it goes the other way (moves his finger to the right).
P: Travels the opposite direction?
J: (Adjusts controls for the field strength.) You see, it's traveling in the opposite direction.

Peter highlighted certain aspects he noticed in the log scenario to James by directly quoting the log (lines 04-05), to which James responded by way of a question on whether or not the fields in both regions were the same (line 06). Peter's response was to directly quote another sentence in the scenario (lines 07-08). He then suggested playing the game (lines 10-11) before discussing the scenario. However James insisted that the scenario showed different fields at work in the two regions (line 15). Peter corrected James and rephrased what was written in the log (lines 16-17). In lines 6-17, we see a trouble in talk or a "hitch in interaction" (Jordan & Henderson, 1995, p. 71) where James questioned Peter twice on whether the fields in the two regions were of the same type (lines 06 & 15) and Peter insisted both times that the fields were indeed of the same type (lines 07 & 16). Although a repair in the interaction was achieved through an implicit agreement to play the game (lines 19 & 20) before resuming discussion of the scenario, the disagreement with respect to whether or not the fields were of the same type still remained.

In this excerpt, we see Peter highlighting textual descriptions presented in the log – the particles were traveling in the same type of field with similar settings. In contrast, he did not highlight information that was visually presented in the scenario – the particles in region A curved upwards whereas those in region B curved downwards. In other words, what Peter fore-grounded was the textual description of the fields in the two regions and what seemed to comparatively remain in the background for Peter were the behavior of the particles in the two regions as represented in the diagram. In order to arrive at an answer to the question presented in the log scenario (why the particles behave differently in the two regions) one has to attend to and coordinate the evidences embedded in the text as well as in the diagram of the log.

Within the first minute of playing the mission, James noticed a new type of particle color-coded blue (line 20). He applied a field on the new particle to see how the particle would behave in it ("let's see what can my field do"; line 21) and commented that it "travels opposite" (line 22), without stating his basis for comparison. In using the indexical term "opposite", it was not clear whether James meant that the blue-colored particles traveled in a direction opposite to that of the *field* or to the direction of *motion of an orange-colored particle* immersed in the same field. Peter did not ask for clarification of what James meant by "opposite".

While Peter highlighted textual information provided in the log (lines 1-17), James highlighted observations he made in the game (lines 20-26). However, no attempt was made to relate the information in the game fore-grounded by James with the information in the log fore-grounded by Peter. In Clancey's terms (2005), to relate these two types of information involves a coordination of perception-conception of the information (e.g. seeing the information as being relevant to the answering of the question at hand and understanding the significance of the information) and action (e.g. comparing and contrasting the information, discussing the implications and drawing inferences). For example, if Peter and James had juxtaposed what the former observed in the log and what the latter observed in the game, the juxtaposition might have led them to a generative discussion that could move them closer to answering the question posed in the log scenario. However, as no apparent coordination occurred between the perception-conception of the information drawn from both the log and the game, and a discussion of what the information they attended to could mean and imply, the question of why the particles behaved differently remained unanswered.

The students went on to focus on completing the level mission for the ensuing 16 minutes, during which the talk focused on the positioning of the fields in order to guide the particles toward the intended targets. The second excerpt we examined occurred at the end of the 16 minutes when Peter again turned to James to ask about the log scenario.

P: (Stops playing the game and picks up his log.) Hey (nudges J), how do you explain the difference in particle behavior?
J: Because there are differences in particles. Simply because they are different particles.
P: Are you sure?
J: Or else, what? It's the same field, the only variable left is the particle.
P: (Remains quiet and wrote on his log: "The particles are different as the only variable left to adjust is the particle's properties. The different particles react differently to the field.")

Peter revisited the question in the log and asked James to explain the difference in the behavior of the particles. During the course of playing the game, James came to a conclusion that the difference in the behavior shown in the scenario was because the particles were different in some way. In coordinating his perception-conception of the behavior of the particles as observed in the game and his action in drawing an inference (line 32), James attributed the difference in particle behavior to the particles being "different" (line 29-30). However, it was not clear what property he was referring to which made the particles "different"; neither did Peter attempt to probe and elicit the property of the particles that made them "different". Instead, Peter posed a closed question (line 31) and James responded by briefly stating his reason underlying his conclusion – "the only variable left is the particle" (line 32). The excerpt ended in silence as Peter continued writing on his log. This indicated yet another missed opportunity for Peter and James to engage in joint reasoning to extend their discussion. A generative conversation could have been fostered by a coordination of the perception-conception of observations made in the game and log with some form of reflexivity whereby learners monitor their progress in the inquiry process. This might have involved the "monitoring of their speech and thought, interrelating alternative viewpoints, evaluating their own and others' performance and displaying an awareness of strategies" (Edwards & Westgate, 1994, p.154). The third excerpt we examined took place about a minute after the second excerpt when Mr. Teo stopped by the group to check on their progress.

T: So, what did you notice about the differences? One is orange, one is . . .
P: One is blue (claps his hands).
T: Other than that?
P: Not much.
T: Only color differences?
J: Reaction to the field.
T: What kind of reaction?
J: Different . . . bad reaction.
T: Bad reaction?
J: Yes.
T: What do you mean by "bad reaction"?

47 J: Because we do not know how to . . . (smiles sheepishly)
48 T: (Pauses, gives a slight smile and walks over to another the group.)

Mr. Teo started by asking them to share what differences the team had noticed regarding the color-coding of the particles (line 36). He followed his first question by prompting the students for other differences that they had noticed (lines 38 & 40). Peter and James did not follow-through with Mr. Teo's attempt to direct their attention to aspects other than the color-coding of the particles. On the contrary, hitches started to appear in the conversation (lines 43 & 45) and despite Mr. Teo's attempts to repair the conversation by asking James to clarify what he meant by "bad reaction" (lines 44 & 46), the students did not try to sustain the discussion. The group missed yet another opportunity for a generative conversation that might have helped them to resolve the question that puzzled them. This pointed to a need for the students to coordinate their perception-conception of observations made in the game and the log with the teacher's confirming, re-constructing, instructional, generative and re-orienting moves (Lidar, Lundqvist, & Ostman, 2006) meant to scaffold their sense-making.

One thing that stood out in all three excerpts was the silence of the third member in the team, Billy. Compared to Peter and James who often engaged in discussions and playful bickering, Billy had a quiet disposition and often played the game silently in comparison with Peter and James who often took turns to give commands on how the electric or magnetic fields should be positioned in order to manipulate the paths of the charged particles. Near the end of the session, Peter asked Billy to show him his log. It was only then that Peter learnt that the difference in the particle behaviors could be due to the difference in the polarity of the charges, as explained in Billy's written response:

> The particles have a different charge. Emitter A emits negatively-charged particles. Even though the field direction is downwards, the particle moves up. Emitter B emits positively-charged particles. These particles tend towards the same direction as the field's direction.

Billy's written response, when contrasted with Peter's (lines 33-35) and James' ("They are different particles") suggested that Billy went a step beyond the conclusion expressed by both Peter and James (that the particles are different in some unspecified way) to conclude that the difference in the behavior of the particles was due to the difference in the polarity of their charges (that one is positively charged whereas the other is negatively charged). Peter and James did not involve Billy in their discussions and neither did Billy volunteer his views and this possibly resulted in a missed opportunity for a generative conversation by the entire group.

Discussion

Clancey (1997) highlights the indexical nature of representations in that the way in which someone interprets a representation, by means of perceiving its form and conceiving its meaning, depends on the ongoing activity. He observed that in inquiry, the "partial understanding shapes the looking and manipulating process" and that "the constructive process is therefore neither top-down from concepts nor bottom-up from perceptions" (ibid, p. 213). This is consonant with the notion that sense-making constitutes and is constituted by a moment-to-moment unfolding of events that shape the trajectory of the sense-making process itself. The hitches in interaction observed in all three excerpts discussed in the preceding section suggest that there was a lack of coordination of perception-conception of information drawn from resources available in the game and the log and the actions associated with scientific inquiry processes (e.g. act of observing, explaining etc), leading to missed opportunities for generative conversations. We suggest that in a game-based learning curriculum focusing on sense-making through scientific inquiry processes, the sites of successful coordination between perception-conception and actions are also the potential sites for generative conversations (Figure 3). Table 2 summarizes examples of successful coordination that potentially lead to generative conversations.

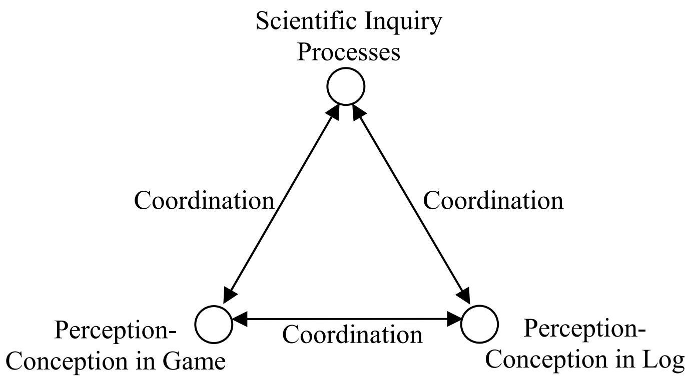


Figure 3. Sites of coordination of perception-conception with actions associated with scientific inquiry.

Table 2: Examples of successful coordination and potential sites for generative conversations

Coordination	Examples
Coordination between perception-conception of observations in the log scenario with actions associated with scientific inquiry processes	• Making observations of textual information as well as graphical information in the log scenario • Reflexive monitoring of the process undertaken by the group in drawing upon the resources available in the form of the log and in the form of discussions with peers and with the teacher
Coordination between perception-conception of observations in Game with actions associated with scientific inquiry processes	• Setting up scenarios (based on those shown in the log or new scenarios designed by students) in the game to investigate particle behavior or to resolve disagreements • Making observations of particle behavior in the game • Reflexive monitoring of the process undertaken by the group in drawing upon the resources available in the form of the game and in the form of discussions with peers and with the teacher
Coordination between perception-conception of observations in the log and perception-conception of observations in the game	• Forming connections between what is observed in the log scenario and what is observed in the game • Using the log as a record of observations made in the game, and explanations and generalizations of particle behavior in fields

The reason why the particles at regions A and B showed different behaviors even though they were in the same type of field with the same direction and field strength was due to the difference in the polarity of the particles. The process of arriving at such a conclusion is not a straightforward one. The missed opportunities for generative conversations which curtailed the group's sense-making trajectory suggest that the coordination of resources in the game and the log with the actions associated with the scientific inquiry processes should not be taken for granted.

Missed opportunities for generative conversations observed in this paper point to a possible area for future research – how developers of game-based learning curricula and teachers may better scaffold and facilitate discussions among students that are more reflexive in nature. This entails fostering skills that enable students to evaluate their own progress during the inquiry process with respect to cognitive (e.g. formulation of questions, use of evidence, reasoning), social (e.g. management of group processes) and epistemological (e.g. interrogation of science as a way of knowing) aspects (Grandy & Duschl, 2007). Much of the type of science inquiry learning which takes place in schools focus almost exclusively on the conceptual structures and cognitive processes involved in scientific reasoning and almost entirely ignore epistemic frameworks and social processes despite the general consensus that science "as a practice has social and epistemological dynamics that are critical to engaging in the discourse and dialogical strategies that are core of what it means to be doing scientific inquiry" (ibid, p. 155). This further underscores the need for fostering greater reflexivity among students during sense-making so that they gain an embodied understanding of the phenomena being studied and for developing scientific inquiry practices.

Conclusion

In this paper, we described the *Centauri Learning Program*, a game-based curriculum designed around the use of a multi-player 3D game *Escape from Centauri 7*. We examined the interactions among the students as they collaboratively engaged in scientific inquiry processes through game-based learning while enlisting the resources available in the form of the 3D game and the associated curriculum materials that act as scaffolds. We identified potential sites for generative conversations that shape their sense-making trajectories of unfamiliar phenomena by studying the students' coordination of perception-conception of information and their actions related to scientific inquiry processes. Future developments to the *Centauri Learning Program* may focus on the fostering of greater reflexivity among students as they participate in scientific inquiry.

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