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ABSTRACT
            Open-ended learning environments (OELEs) like
microworlds have been touted as one approach for blending learning
theory and emerging technology to support the building of
student-centered understanding. The learning process involves
developing a theory-in-action--an intuitive theory that is generated
and changed by learners as they reflect upon experiences that either
confirm or challenge the validity of the theory. The purpose of this
study was to investigate how theories-in-action develop in
collaboration with open-ended learning environments. The study
examined the following questions: (1) What processes are used by
learners to build and/or evolve a theory-in-action? (perception,
organization, integration); (2) What intentions are used by learners
to build and/or evolve a theory-in-action? (unsystematic searches,
goal-based intentions, means-based intentions); and (3) How do
learners use system features to build and/or evolve a
theory-in-action? (awareness of features vs. awareness of how to use
them to accomplish goals or test a hypothesis). Participants were
four seventh-grade students drawn from a general science class.
Findings were organized according to an analysis of system-based
events, learner processing of events, and learner intentions for
action. Results indicate that the process of developing
theories-in-action in conjunction with OELEs appears to center around
three primary areas: decisions about how to use the system;
processing of system-generated feedback; and intentions for further
action. The more closely linked these three components, the more
likely a theory-in-action will develop and evolve. Further discussion
focuses on over-reliance on visual cues and on the discovery of a
situated learning paradox. (Contains 15 references.) (AEF)

Title:

The Process of Developing Theories-in-Action with OELEs: A Qualitative Study

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Introduction

Open-ended learning involves self-directed processes that are driven by the unique intentions and purposes of learners. Contemporary learning theory such as constructivism (Jonassen, 1991), situated cognition (Brown, Collins, & Duguid, 1989), and cognitive flexibility (Spiro, Feltovich, Jacobson, & Coulson, 1991) emphasize the active role of the learner in constructing understanding. Furthermore, theoretical perspectives about student-centered learning have become increasingly foundational for contemporary technology-based environments such as microworlds (Papert, 1993) and anchored instruction (Cognition and Technology Group at Vanderbilt, 1992). Open-ended learning environments (OELEs) have been touted as one approach for blending learning theory and emerging technology to support the process of building and evolving student-centered understanding.

OELEs use technology to create experiences for learners to build and test their intuitive notions about the world. Microworlds, for instance, use technological environments wherein learners can begin exploring and building upon intuitive models (Rieber, 1992). OELEs are based on an assumption that learning is a continuous and dynamic process that constantly evolves as a result of a learner's observation, reflection, and experimentation (Hannafin, Hall, Land & Hill, 1994). OELEs are designed to provide experiences for learners to identify, question, and test the limits of their intuitive beliefs and theories. As such, the learning process involves developing a *theory-in-action*--an intuitive theory that is generated and changed by learners as they reflect upon experiences that either confirm or challenge the validity of the theory (Karmiloff-Smith & Inhelder, 1975).

Piaget (1976) characterized the learning process as one that occurs through continuous testing and reconciling of beliefs in the face of ever-changing experience. Understanding is constructed from initial intuitions that are built upon by learners as they encounter experiences that lead them to question the adequacy of their "theory." Once the theory is questioned, understanding develops as learners confront their theory through a series of actions designed to test it. Corrections to the theory can be made as learners connect thinking and action by testing the limits of the theory.

The Problem

The process by which learners use OELEs to build and evolve new models of understanding has not been studied extensively. Despite the theoretical ideals of OELE's, the process by which learners interact with these systems to build an initial theory, test it, and revise it remains unclear. Some studies have indicated that learners do not use system features in ways conducive to building understanding (Atkins & Blissett, 1992). A greater understanding of how learners use OELEs to build and evolve theories-in-action is needed.

Previous research has provided little insight into the *process* used by learners to build and evolve theories or models of understanding. This study was less about examining the extent of a learner's understanding than about empirically documenting the dynamic process of conceptual development as it occurs in conjunction with an open-ended learning environment. The study qualitatively examined how the organization of learner actions within an open-ended system gave rise to new understanding that regulated the development of a theory-in-action.

The Purpose

The purpose of the study was to investigate how theories-in-action develop in collaboration with open-ended learning environments. The study examined the following questions:
1. What processes are used by learners to build and/or evolve a theory-in-action?
2. What intentions are used by learners to build and/or evolve a theory-in-action?
3. How do learners use system features to build and/or evolve a theory-in-action?

Method

The participants were 4 seventh-grade students drawn from a general science class. The students were studied as separate cases. The learners included two boys and two girls. The OELE was the *ErgoMotion* level III interactive videodisk (mechanical physics), which combines computer-generated graphics, computer simulations, video and print-based materials. The content of the OELE is physics (force and motion), and learners construct understanding of these concepts by designing a roller coaster. Learners use the environments by manipulating variables such as amount of mass, curve radius, and hill sizes. Informational resources are also embedded into the program such as on-line

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consultants and a "videopedia." The primary techniques for collecting data included think-aloud protocols, observations, and interviews.

Learners used the system for approximately four hours, and the sessions were videotaped and later transcribed. Interviews took place approximately one week later, and learners were given analog problems of physics concepts, a perception of open-ended learning questionnaire, and a feature knowledge questionnaire. Learners were led through videotapes of their sessions, and were asked to clarify their thinking and intentions. Interviews lasted approximately 2 hours.

Findings and Implications

Findings were organized according to an analysis of system-based events, learner processing of events, and learner intentions for action. The analysis used detailed data from verbal protocols to examine individual actions and the intentions and processes that gave rise to them. The goal of the analysis was to identify and represent how actions, processes, and intentions formed on a micro-level during open-ended learning, in order to derive a theoretical framework to better understand cognitive processes at a macro-level. The data were assigned to categories that represent the extent to which a learner builds and evolves a theory-in-action.

Question 1: What processes are used by learners to build and/or evolve a theory-in-action?

This question examined the extent to which a learner processed system feedback resulting from taking action. Three levels of processing distinguished the ways that learners processed information during theory development. Specifically, learners *perceive* relevant conceptual information, *organize* the information around interpretations or explanations, and *integrate* information with existing prior knowledge (Mayer, 1989). Responses were identified as instances of processing if they represented cognitive reactions to information or feedback provided by the system.

Perception. At a minin m, all learners processed information at the perceptive level. Most learners recognized the effects of their actions on system events. For instance, one learner perceived visually that variations in mass and horsepower resulted in less time for the coaster to reach the top of the first hill:

> I thought that the more mass that was in there [with a 50 versus a 25 horsepower engine], it took it a while to get up there. So I'm now going to change the horsepower to 100.

In this case, he selected the information that was relevant (i.e., changed the horsepower), and derived conclusions regarding its effect on the coaster. This learner used observational data generated by the system to draw a valid conclusion about this observation.

Learners often made valid conclusions concerning their observations, in the form of either success or failure of the coaster, or verbal or numerical information provided by the system. On the other hand, learners frequently drew erroneous conclusions based upon their observations. Learners frequently confounded visual information with judgments based upon subjective, naive, incomplete or inaccurate visual information. Confounded observations were frequently used to describe the behavior of the coaster in subjective and inaccurate ways (e.g., "It's gaining speed at the very end"). For instance, after lowering the horsepower and observing the coaster crash, one learner concluded, "It went further this time [around the curve]." Objective data for drawing valid conclusions (i.e., the coaster crashed) were confounded with subjective perceptions of visual information (i.e., it went further). In this instance, perceptions of inaccurate data resulted in erroneous assumptions about the effect of horsepower on the speed of the coaster (i.e., it went further after lowering the horsepower; therefore, horsepower must affect speed).

Organization. Most learners attempted to assign meaning to system events by generating interpretations, expectations, or evaluations based on system feedback. Learners used organizational processes to establish simple cause-effect relationships and expectancies. For instance, they learned quickly that when the coaster moved rapidly during the simulation, it was likely to crash. Thus they formed a simple expectation that was easily confirmed, based on whether or not the coaster crashed. Statements of expectancy such as "It's going to fall off," "I didn't think it would make it," and "I knew it would go over" were used often used to establish and confirm rudimentary expectations about whether or not the coaster would "work."

Eventually, learners used information from the system to form simple cause-effect relationships. They provided a reason or cause for a system event (e.g., "Yeah, it was probably too much horsepower going up..."). Simple cause-effect interpretations were usually based on intuitive ideas about the cause of a coaster crash. For instance, one learner

tried to stop the coaster from crashing for several trials before offering an explanation: "I figured out what I did wrong. There wasn't enough weight." Based on this interpretation, she took action to increase the mass. In a similar instance, another learner remarked, "I think the engine's too [powerful]," and lowered the horsepower accordingly. In these instances, learners offered an explanation for the event, but did not provide observational evidence to support their interpretation. However, the interpretation or expectation was used to take future actions.

Learners frequently interpreted system feedback based upon preconceived assumptions or beliefs. To illustrate, one learner's subjective interpretation of system data was evident in his statements about the role of mass and speed: "I think that with more people, it went a little bit slower than what it did without less people ... The more mass you have on it, like the slower it will go." During his next interaction, he changed the hill sizes "to get more speed" and decreased the mass. He remarked,

> I'm going to try it with no people on it...with the same engine ...[runs simulation; coaster is successful] Hmm... It went faster than the one with the people on it....Yeah, I think it might have [gone] faster than the one with people on it, but because of the hill size I have, with the smaller hill up here (hill 3), it went slower, a little bit, than it could have went.

In this instance, he appeared to interpret visual cues from the system in ways that were consistent with his intuitive assumptions about factors affecting the speed on the coaster (in this case, mass). The consequence of his intuitive perceptions was faulty interpretations regarding causes and effects. In such situations, it appeared that learners "saw" what they intuitively expected to take place, and consequently derived perceptions and interpretations of visual cues that were consistent with these assumptions. Consequently, learners were often unable to use system feedback to further revise and refine interpretations.

Learners also elaborated and/or confirmed expectations using intuitive assumptions and beliefs not generated from objective data. They tended to elaborate and change interpretations in ways that were consistent with their intuitive expectation. When an expectation was not confirmed by system feedback, learners often changed or added to interpretations, in order to make them consistent with the new data. For instance, one learner encountered the following actions, each of which was sparked by inconsistencies between observed data and expectancies:

> I'm going to put more weight on there. So it's like a full cart, I guess. [runs simulation] It's going to go off that track. [crashes]. I guess you just can't have that much power on. I'm going to put a smaller engine on there... So with a smaller engine, I think it will stay on the track. [crashes]. I think since it had so many people on it, ... it makes a lot of force ... with all the weight.... I'm going to try it with less people... Maybe it will stay on. [crashes] .... I guess .. even with the smallest engine, all that weight on it, is... playing a big part in making it go off.... With an engine with no people on it, I don't think it would go off. Yeah, if it didn't have any people in the cart, it wouldn't go off. I'm going to try it with a little less people in it. [crashes] Now I know ... now I think it's like ... I think it's the *hills* [italics added] now. Cause even with less people on there ... with the real steep hills, it's getting too much speed.

When expectations were not confirmed, this learner appeared to either create new expectations or add to the previous ones in ways that preserved his underlying assumptions. As inconsistent data continued to challenge his assumptions, his expectations about the importance of mass and horsepower may have weakened, but were not altered. This was further evidenced by an interaction that took place shortly after, when he tried to determine why the coaster did not ascend the third hill.

> It didn't even have enough power to make it up that real steep hill. So, I'll make [hill 1] steeper...[goes to energy loading] Well let me try something. [changes horsepower from 25 to 50] I think it might have more power now, and then I can leave it like that and it might go over. [coaster does not make it over hill 3]... Well, I think I'll not make [hill 1] the steepest ... but make it a little bit steeper.

He returned to his assumptions about horsepower to interpret events and guide future actions. These examples suggest that powerful intuitive assumptions drive both interpretations about the reasons for actions and decisions about future actions, and are not easily altered.

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Integration. Integration involved connecting actions, concepts, or system events to prior knowledge or relevant personal experiences, which were used to interpret, evaluate, or supplement conceptual understanding. Integration relationships were evident in references to analogies, metaphors, or concrete personal experiences (Mayer, 1989). In comparison to other processing levels, learners showed little evidence of integrating system events. Those who integrated often used their experiences of riding roller coasters to elaborate the data. Sometimes, however, prior experiences with roller coasters contradicted the system experiences. For instance, the solution to one of the "coaster challenge" problems was to arrange the sizes of three hills so that the coaster would roll backwards down hill 3, roll backwards over hill 2, and come to a rest in valley 1. One learner initially wanted to attempt this, but remarked:

> Oh yeah. It's got brakes, it can't roll backwards ... They told us that because there was this one lady who was freaking out before we went on a ride. And they said, "it's got automatic brakes along the edges, and it if stops, it will clamp and you'll hang."

She continued to make references to brakes and clamps during remaining use of the system when addressing issues of slowing down and stopping. Prior knowledge, in this case, appeared to limit interpretations and future actions due to inconsistencies between personal experience and the environment.

Two learners related observations or interpretations to personal experiences. In reference to information provided by a consultant on acceleration, one learner remarked: "I was thinking about when you're in a car or something, how when you like go faster ... it will like push you back in your seat, and when you come to a stop sign, you will go forward." After listening to information from the on-line consultants on "what affects acceleration," he added: "I've got a dirt bike, and when you go faster, it kinda pushes you back ... like pushing on you a little bit." In this instance, he clearly linked the concepts presented in the system with his own personal experiences.

Question 2: What are a learner's reasons intentions for building/evolving a theory-in-action?

Intentions represent a *reason* for action. Intentions *can* mediate a learner's actions and the processing of information resulting from them. Three levels of intention distinguished the ways that learners used information to regulate future actions: Unsystematic, goal-based, and means-based. In unsystematic searches, learners browsed the system with no apparent intention to either meet a specific goal or understand relationships. With goal-based intentions, learners focused on taking specific action to meet a specific goal (i.e., to make the coaster "work"). Means-based approaches focused on taking action to discover *why* an event is occurring or what *could* happen if limits were extended. The search for means implies a goal of confirming or refuting a theory (Karmiloff-Smith & Inhelder, 1975).

Unsystematic searches. All learners conducted unsystematic searches during the learning process. Such intentions often took the form of "browsing" the system features and trying to determine their functions (e.g., "...see what this does."). Often, unsystematic intentions were manifested in situations where uncertainty existed about how to solve a problem. For instance, one learner explored the menu bar and attempted to use a video grabber tool to help him solve the problem. He stated, "I don't know what that is ... I'll try it I guess." Still unable to solve the problem, he later tried the grabber tool again, and frustrated, remarked, "What is that *grabber* [italics added]?"

Goal-based intentions. The focus of goal-based intentions was to find out what "worked" and to take subsequent actions. Learners often set goals and took actions to meet them, noting actions that did, and did not, prove successful. For instance, after a coaster crash, one learner remarked, "Well, I found out what hills don't work here." He then wrote down his "answer" and left the coaster site shortly thereafter to "[go] back to my questions and answer another one." In these instances, goal-based approaches were used test ideas about what might work. The reasons for success were not addressed; rather, information about the success was noted and recorded for later reference.

Means-based intentions. All learners demonstrated means-based intentions, but to varying degrees. Means-based intentions were identified when learners developed new intentions to explore the limits and boundaries of actions, rather than focusing on what is "known" to solve the problem. For instance, one learner had the following interaction:

> [coaster crash] I figured that might happen. Yeah, it was probably too much horsepower going up and all ...
> When you first start off going up the hill, it's pushed so fast, and you've got all that force from the first hill, because I made it real steep ... [changes horsepower to 25] I made it so I dropped the horsepower of the engine, and I made the first hill smaller, so it will probably stay on the track. [coaster makes it]

In this instance, Jason elaborated a clear expectation or theory as to why the coaster crashed, and offered an alternative he anticipated to result in success. Following success, he continued exploring alternative solutions:

> [makes curve small and runs simulation] I think it's going to go off the track. [crashes]. Well, yeah, with that sharp of a curve, and it had that much speed going... I'm going to make [the] hills smaller, so maybe even with the sharper curve, it will stay on the tracks. [coaster makes it] I kinda figured that one [would work], 'cause ...the first hill was not ... so steep... [changes mass to 6000]. I'm pretty sure this one will stay on. With that many people on there, it will... make it slower and all. Yeah, and... maybe also because [the first hill] wasn't very steep.

During this interaction, he acknowledged that the sharpness of the curve caused the coaster crash. However, rather than changing the curve, which would be the likely choice for success, he changed the hill sizes to explore the limits of the curve's capabilities. In this instance, this learner appeared to evolve his intentions from choosing the most likely solution to finding alternative solutions.

Question 3: How do learners use system features to build and/or evolve a theory-in-action?

Feature use distinguished the ways learners responded using the features and functions of the system. Feature use was defined operationally as the way in which learners used the system to meet a goal or intention. Three categories were developed: (1) general awareness of the existence and function of a feature; (2) awareness of how to use a feature to achieve a desired goal; (3) awareness of how to use a feature to build, test, or evolve a theory.

General awareness of existence and functions of a feature. During the interviews, learners were asked questions about their awareness of system features. All indicated at least minimal awareness of primary system features. Even when system features were not used, learners responded in the interviews that they knew that they existed. For instance, none of the learners except one used the coaster's features to gather numerical information about the speed, g-forces, kinetic and potential energy, and acceleration at given points along the track. One learner explained his awareness and reasons for not using them:

> Researcher: There are data points under the options menu, and it puts these little hot spots all along the ..
> Learner: Oh yeah, yeah.
> Researcher: So you knew about that. But you didn't use it.
> Learner: Yeah ... I guess I just didn't think I needed those data points to help me. I think that if I really thought about it, I could just figure it out on my own.

Another learner responded in a similar manner, noting " .. I guess I just thought I could manage without them." Such responses may imply that learners view system features other than primary manipulation tools as needed only for assistance.

Awareness of how to use system features to meet a goal. Feature usage was most apparent in situations where learners verbalized a specific intent or goal, and then told how they would use the system to achieve it. At other times, learners perceived that the system could not provide the information needed to meet a goal. This was evident even when the system could provide the information desired, but learners were unable to recognize that the information was accessible. For instance, one learner stated, "I wish I knew what motor we were using on this." [Although the information was not displayed at that moment, it was available in a different section (at the energy loading section)]. This learner did not know how to maneuver the system resources, tools, and features in order to solve her problem, even though she was aware that the features existed. In this case, the system provided neither the information she sought nor cueing to possible features for answering her questions.

One learner encountered a situation where the information was immediately available, but was not represented in a form she could recognize. As the following interaction illustrates, she did not find the information useful:

> [sets hill heights at hills and valleys section] Yeah, that would be fine, it would just take them longer ... to cover the track. I wish .. it would tell me how much time it would take ... Well, I can look at the data points. [views data points, then runs simulation]. Oh I wish it would tell me the time it took for it to run the full course ... Then I'd be able to tell which one was faster.

The information on the roller coaster's speed was available for each point along the track. This learner, however, sought a specific form of the data, one that was not represented.

Awareness of how to use system features to build, test, or evolve theory. Awareness of how to use the system to develop and test hypothetical situations was not apparent. Learners offered theories or reasons for the consequences of an event, held that predicted variable constant, and intentionally tested it using manipulation tools of the system. However, they did not use system features to derive and test hypothetical problems or to derive counter-examples to confirm or refute a theory.

One learner, for instance, often used the system to test and revise hypotheses:

> [sets hills] I'm not sure if it will even make it over the hill. [coaster stops at top of hill 3] ... 'cause that first hill is like shorter than the third hill ...[changes hill 1 to medium; stops at top of hill 3] Still didn't make it. Add more horsepower to it [changes horsepower from 25 to 50]. *Still* [italics added] didn't make it ... Change the weight on it [changes mass from 6000 to 4000 kg]. I think it will make it over now. [stops at top of hill 3]. Yeeee... nope. [changes mass to 20000 kg.; still does not go over hill 3]... Well, if I change the horsepower, it might make it over the hill. [changes horsepower to 100]. [stops at top of hill 3]. St.!l didn't do it. Change the ... hills I guess.

After lowering hill 3, the coaster run was successful. However, despite evidence that could be used to question the validity of his horsepower theory, this learner did not use the system to confront his faulty assumptions. That is, he did not try to construct a hypothetical counter-example to see if the horsepower affected acceleration in the ways he believed. It is also interesting to note that this learner successfully answered a question in the Science Talk Show about the whether doubling the size of the motor was necessary if doubling the hill size. It appears that he acknowledged the relationship between horsepower and acceleration on an abstract, conceptual level, but did not recognize the information as counter to his theories about horsepower. Due to apparent difficulty in recognizing counter-examples, it is not surprising that learners failed to use the system to systematically construct and test them.

General Discussion

The process of developing theories-in-action in conjunction with OELEs appears to center around three primary areas: Decisions about how to use the system, processing of system-generated feedback, and intentions for further action. The more closely linked these three components, the more likely a theory-in-action will develop and evolve. The model presented in Figure 1 illustrates the interplay between the system and the learner in developing a theory-in-action.

Figure 1: A conceptual model of the theory-in-action development process
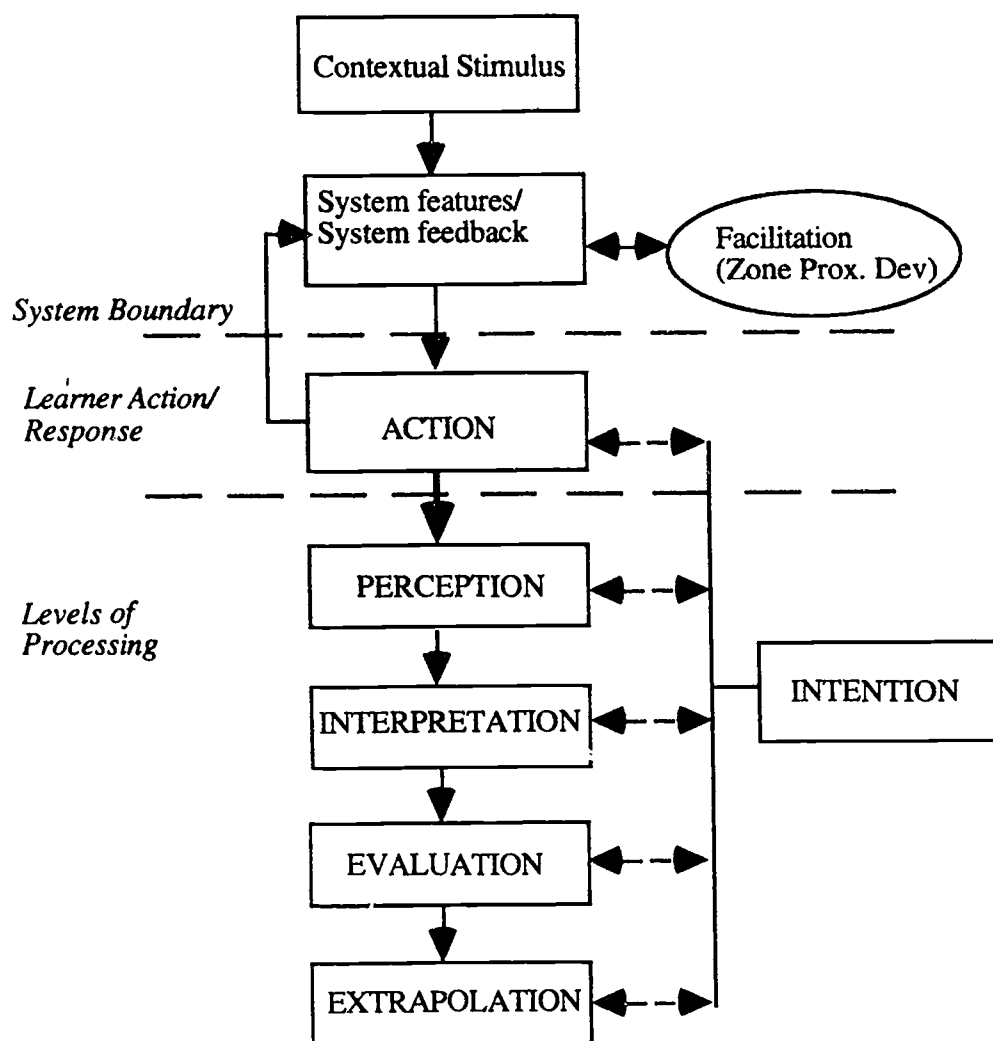
The model predicts that as learners progress in their understanding, underlying theories are built, confirmed, and/or refuted. An initial theory-in-action is *built* iteratively through basic levels of processing, perception and interpretation, which are informed through learner intention and action. Learners *perceive* relevant information from the system, use their intuition and prior knowledge to provide *interpretations* to explain system events, and establish *intentions* to take *action* using system features to test their interpretations. A refined theory-in-action *evolves* as learners: (1) *perceive* information as consistent or conflicting with their theory; (2) *interpret* a new theory or elaborate an existing one; (3) *evaluate* the validity of the theory using new data; (4) *extrapolate* alternative rules or explanations; (5) use *intentions* to expand the predictive boundaries of the theory; and (6) take *action* to test their previously-held or new theory. The study uncovered several prominent findings with significant implications for understanding how learners build and evolve theories-in-action with OELEs.

The Resilience of Theories-in-Action

An important implication of the study is that theories-in-actions were extremely resistant to change. Whereas learners showed evidence of building theories-in-action, they did not appear to evolve them significantly. Through interaction with the system, learners became more *aware* of their intuitive theories by using them to explain system

events; they did not, however, recognize limitations in their predictive value and attempt to refine them further. Learners hold powerful personal theories that often dominate cognitive processes and actions with OELEs. Even with system tools to manipulate and evolve conceptions, initial learner theories remained largely unchanged. Learners did not use system tools to manipulate the theories; instead, they tended to manipulate the system and interpretation in order to preserve them.

The Over-Reliance of Visual Cues from the System

Another prominent finding was that learners relied heavily on the video simulations to provide feedback about a previous action. Learners used the video segments literally to estimate the speed of the coaster during the simulation and the probability of its crashing (if it was moving rapidly on the simulation, it would crash). Learners also used visual cues to interpret the speed of the coaster, and judge relative differences in speed.

A reliance on the literal interpretation of visual cues is likely due to novice learners' focus on superficial or surface features of a problem (Chi, Glaser, & Rees, 1982). It is often difficult for novices to select relevant information, and they typically interpret visual symbols as relevant (Petre, 1995). Accordingly, novices confuse visibility with relevance, and focus on obvious visual cues, without considering the underlying logic of their selection. This tendency is possibly influenced by frequent exposure to television, videos, and computer games, where learners have adapted to processing obvious visual information without considering deeper meaning.

In the present study, reliance on visual cues was damaging to theory building because the system feedback provided inaccurate simulations of speed. Consequently, learners misperceived the fidelity of the images, and as such, built initial assumptions and theories that were incorrect and difficult to alter. Without accurate and more precise representations of speed, learners could not evaluate limitations in their thinking. When ambiguously-presented data are interpreted literally by learners, theory evolution is stunted due to misrepresented feedback ultimately perceived by learners as valid.

Another consequence of relying on ambiguous and inaccurate visual cues was to "contaminate" or bias learner interpretations (Wilson & Brekke, 1994). In the present study, learners often perceived inaccurate and ambiguous visual information, and used it to preserve or confirm their thinking. For instance, learners typically believed that increasing the mass increased the coaster's acceleration. After running the simulation, they often inaccurately concluded that the video feedback supported the belief (e.g., "...it went faster than the one with less mass"). Consequently, over-reliance on visual cues not only influenced inaccurate theory building, it also preserved it.

The Situated Learning Paradox

One assumption underlying the design of OELEs is that learning is optimized when it is situated in an authentic context (Hannafin et al., 1994). Learning is facilitated when experiences to connect prior and everyday knowledge to new contexts are provided (Choi & Hannafin, 1995). As learners connect system-derived experiences with prior knowledge, they access existing frameworks to be built upon and used to support new understanding. This knowledge can then be used to enrich or elaborate system experiences and intuitive theories.

OELEs use authentic contexts to facilitate the linking of system events to prior knowledge. For instance, the roller coaster site is authentic in that it embeds relevant knowledge and skills and assists learners in connecting system experiences to prior knowledge (most children are familiar with roller coasters). While links to prior knowledge enhance the potential for transfer (Brown, et al., 1989), it also increases the likelihood that learners will draw upon incomplete and often inaccurate understanding which form the basis of faulty theories. Findings from this study indicated that learners often referenced prior knowledge and experiences that either contradicted, or interfered with, the system's treatment of the concepts of force and motion.

Fragmented prior knowledge affects how information is interpreted and actions are taken. For instance, in the present study one learner recalled a roller coaster operator telling her that the coaster had brakes and could stop mid-ride. Consequently, she used this information to interpret feedback and drive future actions. As a result, she often interpreted the coaster as slowing down around curves because of her belief that the coaster used brakes. In this case, a belief that the coaster slowed down around the curve (because of brakes) interfered with an understanding of force and motion in a context that did not support exploration of the notion.

In sum, despite evidence of evolution of theories-in-action, this study indicates that newly evolved theories are fragile and easily abandoned. The strength and persistence of intuitive theories-in-action, in the face of conflicting experiences, raises questions regarding the nature and process of learner cognitive development.

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