Interaction Design and Architecture(s) Journal - IxD&A, N.29, 2016, pp. 24-51

The Interaction between Design Features and Learners' Goals: A Case Study of a Science Museum Game

Cathy Tran[1], Ole Smørdal[2], AnneMarie Conley[1]

[1] University of California, Irvine, USA
[2] University of Oslo, Norway
ctran27@gmail.com

Abstract. The design features of an educational game interact with students' goals to influence their behaviors, and reciprocally, the outcomes of those behaviors dynamically shape their goals. Our study assessed the process of goal pursuit through a fine-grained analysis of motivation using self reports, interviews, and videos. Findings revealed patterns of engagement and disengagement that reflected students' self-reported achievement goals of mastering the content knowledge, avoiding looking incompetent, and/or outperforming others. Those goals behaviorally manifested in the choices that students made about which information to focus on and the types of information to seek while playing a game. To inform future development of educational games, we present a typology of information-seeking behaviors and highlight key design features that support and hinder the pursuit of different goals. These insights expand our understanding of the underlying mechanisms that make balancing learner and player experiences challenging and provides guidance for that integration.

Keywords: motivation, game-based education, information seeking, educational technology

1. Introduction

The impact of video games on motivating players to persist in overcoming failure has generated substantial interest in the potential for using games and game principles to motivate more "serious" undertakings. Literature reviews and meta-analyses about the effects of educational games have concluded that their impact on learning and motivation is mixed, however, with many studies revealing that educational games are often no more effective than other instructional methods [1]-[4]. In explaining the reason for this, Wouters et al. suggest that a greater integration between the fields of game design and instructional design is needed [4]. This effective integration goes beyond superimposing game elements such as points and badges onto existing educational tasks or integrating educational elements such as multiple-choice questions into existing games. Our study addresses the need for identifying the underlying elements and structures that makes game-based approaches successful by analyzing learners' engagement and disengagement through the lens of the Achievement Goal Theory of motivation [5].

Goals are an important consideration because decades of research on student motivation suggest that deep and continuous learning does not depend only on *amount* of engagement but also on *reasons* for engagement [6]. Goals influence what students focus on and how they respond to feedback from both the physical and digital features of the activity [7] and from co-participation and collaboration with others [8]. The design features of an educational game, such as the way the instructions are phrased or the ease of comparing players' scores, interact with students' goals to influence their behaviors. Reciprocally, the outcomes resulting from those behaviors then dynamically shape their goals and goal revisions. To better understand these relations, our study assessed the process of goal pursuit during students' visit to a science museum during a high school field trip. We assessed the ways in which the design of a game interacted with and shaped students' goals in ways that influenced their behaviors. Understanding the ways in which an educational game influences the goals that students adopt and their goal pursuit behaviors contributes to a better understanding of the consequences of the design decisions made in game-based learning environments.

Though students' reasons for engagement are cognitive, those reasons behaviorally manifest in the choices that students make about which information to attend to and the types of information that they seek. These information-seeking behaviors provide insight about students' mastery goals as a learner, their competitive drive as a player, and their pursuit towards those goals. To provide the premise for these connections, in the remainder of this introduction, we first introduce Achievement Goal Theory [5] and explain why its emphasis on the reasons individuals are motivated, as well as the standard against which they judge their success, is appropriate for studying game-based learning [9]. Next, we explain how students' goals can be understood through their behaviors by providing an overview of the research on the relation between achievement goals and help-seeking behaviors. The aim of this paper is to use the research on Achievement Goal Theory and help seeking to better understand the impact of applying game-based elements to a science exhibition and to provide new guidance on how to design for and evaluate learner and player experience.

Consideration of achievement goals for educational game design

We draw on Achievement Goal Theory [5] of motivation to offer researchers, educators, and designers theoretically-grounded constructs that have implications for both studying and incorporating the design of game-based elements in educational settings. Achievement goals reflect the reasons individuals are motivated as well as the standard against which they judge their success. Researchers have distinguished two achievement goal orientations toward learning: mastery and performance. A *mastery goal* focuses on *developing* skills and knowledge whereas a *performance goal* focuses on *demonstrating* competence by outperforming others [10]. Achievement goal adoption is not an all or none affair, as some researchers contend that individuals can endorse many or few and can endorse each goal at varying levels of intensity [11] [12].

The types of goals adopted as well as the intensity at which they are pursued impact the ways students behave towards learning and playing in game-based settings. Students typically endorse multiple goals, though oftentimes one of those goals is more strongly endorsed than the others [11], [13], [14]. Having stronger mastery goals has been linked to positive outcomes, including increased cognitive engagement, deeper cognitive strategies, and greater interest in the subject [15], [16]. For science learning in particular, in a study with middle school students, researchers found that for the topic of science, stronger mastery goals were associated with higher self-efficacy, self-concept, and confidence of one's self-regulation abilities [17].

Performance goals have varying consequences with an important distinction being whether students adopt a *performance-approach focus* on appearing highly competent or a *performance-avoid focus* on not appearing dumb. For instance, performance-approach students may want the highest score in the class whereas performance-avoid students will choose to not study for an exam to justify potential low grades to lack of effort rather than low ability.

In the context of students in a science classroom, performance-approach goals were associated positively with self-concept; however, stronger performance-avoid goals were linked to lower self-concept and confidence of one's self regulation abilities as well as higher feelings of apprehension [17]. Performance-avoid goals are often also linked to negative consequences such as procrastination, putting in little effort, and cheating [18]. Other research has generated mixed results on the associations between achievement and the performance-approach goal orientation, indicating that such orientations are linked to unrealistic high goals in some cases but also to high achievement in others [19]. It could be that the endorsement of the achievement goal orientation of high performance-approach is beneficial when it occurs in conjunction with high mastery goals, as that combination has been linked to both high interest and high achievement in a task [11].

Limited attention has been paid to Achievement Goal Theory and goal change in game-based learning though related work has been done on managing the tradeoffs between fun and work in the design of educational games [20] This area has untapped potential for helping us better understand how to design for learner engagement, especially in game-based learning, because achievement goals are an especially appropriate theoretical framework to use in situations that allow for the achievement of both mastery goals and performance goals.

Fig. 1. A heat pump game as part of a science museum exhibition about future energy.

Taking the example of the heat pump game that is the focus of our study, students can pursue mastery goals of understanding the scientific mechanisms that underlie the functioning of the heat pump through the digital simulations of the inner workings of the heat pump *(Figure 2, left)*. For example, as players rotate a physical metal crank right or left, the simulation shows the resulting changes in the pressure and flow of heat in the depiction of the interior of the heat pump displayed on a digital screen. The game scores *(Figure 2, right)* provide affordances for pursuing performance goals because they reflect how successfully the players were able to operate the heat pump to keep a house at an optimal temperature throughout the year. Since we have two games occurring simultaneously and in close proximity to each other, students are also able to compare their scores with others.

Fig. 2. The display of the heat pump game during play (left) and of the score at the end (right).

Influence of design features and learners' goals on information-seeking behaviors

The design features of a game interact with learners' goals to influence their behaviors, and in particular, shape the type of information sought. To better understand ways designers can leverage these relations, we review the existing theoretical knowledge on the link between achievement goals and help seeking in the classroom and then discuss its implications in the context of designing game-based learning environments.

Research on achievement goal orientations suggests that both individual goals and student perceptions of the classroom contribute to different help-seeking behaviors including choice in source of help (e.g., teachers vs. peers) and choice in type of help (e.g., seeking to quickly obtain the correct answer vs. seeking to understand the mechanisms that underlie the correct answer) [21]. For instance, classrooms that are led by teachers who are receptive to questions and available for assistance encourage students to engage in adaptive help seeking with the goal of understanding how to do a problem [22]. However, classrooms that are led by teachers who are focused on absolute performance and competition result in students seeking more maladaptive forms of help, such as not seeking help at all or seeking help with the goal of quickly getting the answer [23]. These differences in help-seeking actions help explain why students learn and progress at different rates when encountering the same obstacles.

To build on the classroom help-seeking research to better understand how the design of a game influences students' information-seeking behaviors at a science museum, we first broadened the definition of help seeking, which typically includes only the social elements, to also include the non-social components of the process. This is necessary because the non-social feedback from the physical and digital aspects of an educational game is a significant part of the learning experience. Our definition of help seeking therefore encompasses any "process in which humans purposefully engage in order to change their state of knowledge" [24], which involves goal-directed interactions with any information system including humans, computers, and physical manipulatives. Because help seeking is often used in the education research literature to refer to social help seeking, we adopt the term *information seeking* to reflect the notion that both social and non-social help seeking play crucial roles in interactions with educational games.

Games provide a naturalistic way for assessing the effects of the design of a task on information-seeking behaviors because they are deliberately designed to set players up for failure and allow them to experience it, experiment with it, and learn from it [25]. Players engage in rapid and complex interactions as a result of the responsive, adaptive, and interactive components of a game. This is conducive to studying the directed, effortful process of learners setting goals for their learning and then attempting to monitor, regulate, and control their behavior, motivation, and cognition. In our heat pump game, the frequent patterns of information-seeking behaviors that emerged during gameplay allowed us to study how the design of the game affects information seeking and goal regulation. Students incorporate feedback from their successes and failures into their evolving game strategies and goals.

Goals and information seeking processes are dynamic and represent a form of self-regulation [26], [27], and optimal self-regulation entails not only endorsing goals prior to task engagement but also monitoring goal pursuit by evaluating goal progress and contemplating the need for goal revision [28]-[30]. This revision process may be prompted by additional details about the task, available resources, and an evaluative environment. For example, information acquired from additional experience with the task (e.g., difficulty level, usefulness of feedback, competition level) may lead students to adjust their goal endorsement accordingly [31]. Researchers and designers alike need to better understand this process as it is expected that the design of a learning environment would interact with students' achievement goals to influence behaviors and goal change.

Contribution of our research

Our paper, to our knowledge, takes the first step towards understanding the system of ways in which students' achievement goals and the design features of a game interact to influence their behaviors as well as the reciprocal reaction of how the consequences of those behaviors then influence their goals and subsequent behaviors. This research direction builds on decades of work that given us insight on the associations between achievement goals and behaviors. These studies have been predominantly drawn from survey studies about motivation at a large grain size (e.g., for science class). As will be illustrated in our exploratory case study, however, there are exceptions to these broader findings that can be explained by measuring motivation at a smaller grain size (e.g., at several points within a specific task) to allow for a more nuanced understanding of the relation between design, goals, and student-environment interactions. For achievement goals in particular, the extant literature on goal stability and change has been limited in two important ways. First, many have examined shifts in goal endorsement for school across the elementary to middle school transition (e.g., [32], [33]) or shifts in goal endorsement for school within a school year (e.g., [11], [31]). However, few have addressed stability and change in achievement goals across a specific task (for exceptions, see [12], [34]). Second, achievement goal stability and change has been primarily investigated using changes in group means rather than individual differences (for exceptions, see [11], [35]). Addressing those limitations, we continuously examined students' goal pursuit for the full duration of their time spent with the heat pump game at the museum. This allowed us to assess ways in which students' interactions with the design of a specific task influence goal change, providing an understanding of the mechanisms that underlie goal change as well as an understanding of points of leverage that designers may have to influence students' experiences.

Our exploratory study first needed to adopt methods that better align with our theoretical assumptions about ways in which students self-regulate during complex learning tasks. Self-regulatory activities such as planning, monitoring, strategy use, and adaptation all form a dynamic system in which all components influence one another [36]. By using methods that allow us to measure goals and behaviors repeatedly or continuously, we are able to more precisely measure this dynamic process to understand how goals fluctuate in response to learner characteristics and the environment. As such, we chose to supplement achievement goal surveys with second-by-second video analyses and interviews to provide a case study of four high school students during a science museum visit. In particular, we focused on their exploration of an interactive digital game about heat pumps (*Figure 1)* as part of a class field trip. The game is part of a larger exhibit about future energy sources at the Norwegian Science and Technology Museum. Given our study design, in addition to contribution to theoretical advancement of the Achievement Goal Theory and practical implications of educational game design, we also provide insights about using a fine-grained analysis of achievement goals to better understand how design influences it as well as its influence on behaviors.

Research Questions

Our paper investigates the interaction between the student and the design features of the museum space, and use this insight to improve the design of the presentation of the educational content that the exhibit is designed to teach *(Figure 1)*. On the students' side, we focus on how their previous experiences and goals influence the way they interpret the museum space and particularly the game as well as how they "translate" game features in ways that influence them to engage in behaviors that are in alignment with their goals *(Figure 3, RQ1)*. On the museum space side, the design of the game and museum exhibition space itself influence players' behavior regardless of their goals *(Figure 3, RQ2)*. For example, a big screen and a shared space around the game may communicate that it is acceptable and encouraged for others to watch a player engage in a game. As such, both the students' goals and how they interpret the game features influence the player's behaviors. The consequences that emerge from these behaviors then influence the students' goals, such as the player's decision to continue to pursue his or her current goal or to switch goals, and those directions in goal pursuit influence their subsequent interactions with the exhibit. Based on our analysis on the interaction among the student and the design "features" of the museum space *(Figure 3, RQ1 and RQ2)*, we discuss how the design of educational games may be improved *(Figure 3, RQ3)*.

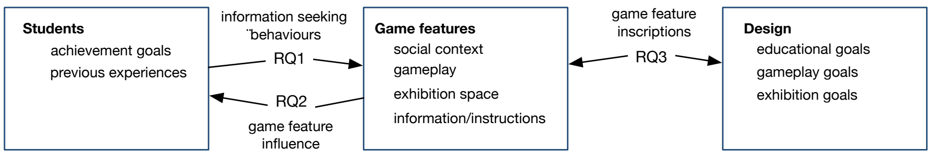

Fig. 3. An overview of how the research questions relate to the interactions we focus.

Using self reports, interviews, and videos to analyze the ways in which learners' goals and the design of the exhibit influenced information-seeking behaviors, our research questions are as follows:

RQ1) What types of information-seeking behaviors do students employ while engaging with an educational game in a museum exhibit?
RQ2) How do game design features influence the way students engage with the game?
RQ3) How does an understanding of achievement goals — and how they align or misalign with game features — improve the design for learner and player experiences?

2. Method

Data for this study were generated from the project Mixed Reality Interactions across Contexts of Learning (MIRACLE). The project aims to increase students' interest in and conceptual understanding of science by connecting science education learning activities in upper secondary schools to technologically-enhanced activities at a science museum [37]. This included a learning trajectory about future energy which aimed to familiarize students about energy transfer and the relation among pressure, condensation, evaporation, and temperature. Energy is one of the main themes in the curriculum for the upper secondary freshmen year in Norway, and heat pumps are one of the sub-themes [38]. The trajectory consisted of three phases: 1) Preparations in the science classroom consisting of experiental learning through operating a bicycle pump and a spray can while feeling the surface becoming warmer or colder; 2) A visit to an energy exhibition at a science museum; and 3) Conceptual activities in the classroom, explaining and making sense of the scientific concepts. We focus on data collected while the students explored a heat pump game during the visit in the second phase.

Context of game and learning environment

In order to present an organized discussion on the relations between achievement goal orientations and game-based learning features, we use a recent review on the design of intrinsic integration of domain-specific learning in game mechanics and game world design [39]. This review discuss educational frameworks for educational game design, and allows us to describe the heat pump game features in terms of the game genre, the design of the gameplay, and the various opportunities for learning while playing the game. The different game features allow us to gain insight about how students use the exhibit in different ways to align available resources to their specific goals as well as how the consequences of their behaviors influence their subsequent goal pursuits during the game. The interactive exhibition about heat pumps was designed by our university lab and the museum as an educational game, with an intention to fit with the learning activities in the other phases in the trajectory. Below, we illustrated ways in which we use an educational frameworks for educational game design [39] to describe the heat pump game features in terms of the game genres, the design of the gameplay, and how opportunities for learning arise while playing the game.

Game genre. The game is a simulation that was designed to be played by one person at a time, rotating a physical metal crank clockwise or anti-clockwise *(Figure 1)*. This action require quick thinking and reflexes. The rotation of the crank is linked to a simulation on the digital screen. The simulation allows students to interact with and discover an underlying, simulated model of the core components of a heat pump, and shows by means of an animation the scientific mechanisms that underlie the functioning of the heat pump and the resulting changes in the pressure and flow of heat. Players, as they crank clockwise or anti-clocwise, can observe how heat is moved from inside to outside and vice versa through processes of condensation and evaporation.

Gameplay. The gameplay consists of two layers, the game mechanics (i.e., game rules and actions) and the narrative (i.e., game-world, scenarios, and the storyline). The storyline is based on the energy needed to keep a house consistently warm throughout a full year using a heat pump to move exactly the required amount of energy from the outside to the inside during winter and vice-versa during the summer. When the game begins, the start screen describes the function of a heat pump before transitioning to a screen of the magnified heat pump with details of its inner workings at the center of the screen. A house and its internal temperature meter are on the left side of the simulation and a meter of the outdoor temperature is on the right side *(Figure 2, left)*.

The game mechanics is based on game cycles, each lasting for approximately one minute. This one minute resembles the duration of a full year, with realistic outside temperatures generated by the game. Players are challenged to keep the house inside temperature constant by operating the heat pump through physically rotating a metal crank underneath the screen in the appropriate direction using the appropriate speed

(Figure 1). Next to the crank are two physical handprints that students can touch; the handprints change temperature to align with the movement of heat in and out of the heat pump. As students manipulate the heat pump compressor using the physical crank to heat up or cool down the house, the heat pump's inner workings dynamically move in real time in the middle of the screen *(Figure 2, left)*. The result screen at the end of the game cycle shows the percentage of time the house stayed within the desirable zone of warmth for each month of a year. The result screen contributes to the storyline by showing the amount of energy saved by using the heat pump *(Figure 2, right)*.

Integration of learning and play in the heat pump game

In describing the heat pump game experience, we adopt five emergent themes from a recent review related to design of learning-play integration in digital games [39]. We find these categorizations useful for presenting and positioning the heat pump game in terms of the integration of learning and play:

The heat pump game as knowledge activation and acquisition. The heat pump game was designed to fit with the curricular demands of the classroom, and the visuals resembled those in the students' science textbooks *(Figure 2, left)*. We expected the visualization of hot and cold surfaces to activate knowledge from the experiental learning that took place in the science classroom prior to the museum visit.

Learning integration via a heat pump simulation. The game was designed to explain energy transfer and the relation among pressure, condensation, evaporation, and temperature by means of an animation that showed condensation as bubbles forming from gas in a cold environment, while evaporation was shown as gas forming from liquid in a hot environment. In addtion a pump and a pressure regulator completed the heat pump animation *(Figure 2, left)*. The animation is interactive, as the pump is continously animated in response to the direction and speed of the player's rotation of the physical crank.

Learning spaces contrived by game mechanics and game world. The heat pump game can theoretically be played without any knowledge of the underlying scientific phenomena of a heat pump because students do not need to pay attention to the inner heat pump animation that depicts the science. Memorizing how to adjust the speed and direction that needs to be cranked each month to match the temperature curve on the screen is sufficient to score highly.

Meta-reflective and iterative learning moments during game play. The result screen may contribute to learning by charting the amount of energy saved by using the heat pump, when compared to alternative forms of temperature regulation *(Figure 2, right)*. The social context of the game, being situated in an exhibition space, is also crucial for reflection and iterative learning moments, as we will present below.

In-game learning support. The alternating displays of the animation during play and the charts on the result screen has a potential for in-game learning as a player may use the result screen as feedback for her or his strategies regarding the speed and direction of cranking. Further could touching the two physical handprints *(Figure 1)* remind students of previous experiental learning in the science classroom related to temperature change and pressure.

Each student in this study visited the heat pump exhibit for about 15 minutes, as part of a group of five students. During this time the game was played multiple times by many of the group participants.

Participant selection

The four key participants in our study were chosen from 32 first-year students (16 of each gender, ages 15 and 16) in one science classroom at a moderately selective high school in Oslo, Norway. The school is one of the new schools in Oslo between east and west and has a mixed population. The teacher and his students were recruited to the MIRACLE project due to their availability and willingness to be part of a rich data collection and intervention study in the context of the everyday activities of a science classroom and in a context of a museum visit.

We administered a self-report measure of achievement goal orientations for science learning prior to the museum visit to identify students with different motivational profiles. The nine-item measure was a Norwegian translation of the Achievement Goals Questionnaire [40], adapted to focus on achievement goals during science class. Items assessing mastery, performance-approach, and performance-avoid goals were scored on a 7-point Likert scale ranging from 1 (*not at all true for me*) to 7 (*very true for me*). Mastery goals focused on learning and understanding (e.g., “My goal in science class is to learn as much as I can”); performance-approach goals focused on demonstrating ability and outperforming others (e.g., “My goal in science class is to look smarter than other students”); and performance-avoid goals focused on not looking dumb (e.g., “My goal in science class is to avoid looking like I can’t understand the material”). There was acceptable internal consistency for the performance-approach ($\alpha = 0.81$), performance-avoid ($\alpha = 0.76$), and mastery scales ($\alpha = 0.83$). Previous factor analyses with larger samples support that the Norwegian translation of the achievement goals measure resulted in unidimensional constructs [41].

We selected four students to focus on because they represented a diverse set of motivational profiles, allowing us to assess the ways that the design of the exhibit influenced different interaction patterns. Each student endorsed one of the following motivation profiles: 1) predominantly mastery oriented; 2) predominantly performance-approach oriented; 3) predominantly performance-avoid and mastery oriented; and 4) similarly performance-approach, performance-avoid and mastery oriented.

Our analyses focused on these students’ interactions with classmates in the groups they were assigned to during a field trip. The manuscript’s authors were blind to the profiles of the selected students while they analyzed the data. Selecting participants based on different motivational profiles allowed us to capture a broad range of learner and player experiences to better understand the impact of design decisions.

Analytical methods

Our analytical process combined data from the self reports about achievement goal orientations, video analyses of the museum visit, and student interviews after the visit. The self reports allowed us to identify students who endorsed different levels and types of goals in order to assess how the design features of the exhibit related to interaction patterns across students of different motivational profiles. The videos of the students' visit at the heat pump game booth allowed us to identify the different types of information-seeking behaviors that emerged. Finally, there were instances during video analyses in which there was insufficient details to determine if there was intent to seek information, and if so, what information was being sought. The one-on-one student interviews after the visit allowed us to show those ambiguous clips to students so that, if they were able to recall their thinking, they could explain what prompted their behaviors during those episodes. This helped us better understand their goals and determine whether to classify those episodes as information-seeking behaviors.

Fig. 4. Heat pump simulation game setup at the museum with two identical games back-to-back.

Interaction analysis of video recordings. Interaction analysis [42] is a method that emphasizes the patterns of the interaction of individuals with one another and with objects of their environments, noting which resources and conversations get taken up and how. This includes talk, nonverbal interaction, and the use of physical (e.g., heat pump crank) and digital (e.g., heat pump screen animation) artifacts. The aim is to uncover activity patterns that emerge as the analysis proceeds to identify routine practices and problems within the game and the resources for their solution. Using principles of interaction analysis, we looked at two groups of five students interacting with back-to-back heat pump games *(Figure 4)*. Each group spent about 15 minutes at the heat pump game and all interactions with our four target students were included in the analyses.

Interaction analysis aligns with our goals to identify how design features and the social environment interact to support or hinder the pursuit of different types of goals.

The bottom-up procedure is appropriate given that our context of a game at a science museum includes resources that are very different from the resources in contexts commonly reviewed in the help seeking and information seeking literature such as classroom environments and internet search engines. As such, in categorizing information-seeking behaviors, we remained open to how the categories might emerge within our data. The patterns of behaviors emerged as we identified key activity episodes that promoted or inhibited goal pursuit and analyzed the interactions prior to, during, and after those episodes to determine how particular game design features facilitated information-seeking behaviors and how patterns of information-seeking behaviors relate to student goals.

Furthermore interaction analyses allow us to effectively study goal maintenance and change. Current measures of achievement goals, which predominantly rely on self-reports administered a few times a year, are appropriate for measuring goals at a larger grain size. For measuring task goal change, however, it is necessary to use measures that are specific to the grain size of the task and that are more frequently employed. Therefore, it is necessary to adopt methods that better align with our theoretical assumptions about ways in which students self-regulate during complex learning tasks. Self-regulatory activities such as planning, monitoring, strategy use, and adaptation all form a dynamic system in which all components influence one another [36]. By using methods that allow us to measure goals and behaviors repeatedly or continuously, we are able to more precisely measure this dynamic process to understand how goals fluctuate in response to learner characteristics and the environment.

To continuously measure goals, we coded information-seeking behaviors and traced the types of conversations that students engaged in or disengaged from as indicators of their achievement goals. For example, a student may seek information to understand the scientific mechanisms of the heat pump and disengage from a group conversation that is focused on game score, indicating a pursuit of a mastery goal. The advantage of measuring achievement goals through video data is that one does not interrupt the process of learning and that one is able to analyze the behaviors before and after goal pursuits to extract information on how the environment may have influenced goal maintenance and goal change. A distinct advantage of observational methods is that they can provide rich description of different levels of engagement in the learning context [43]. As illustrated in our case study, in addition to expanding our understanding of goal pursuit, this smaller grain size of analysis also provides details about specific instances in which designers may have leverage to influence learners' goal regulation.

Our collaborative analysis process followed the precepts of interaction analysis for understanding everyday work practices and human-machine interactions [42] [44]. First, a project staff prepared transcripts of utterances for the recorded footage. The manuscript authors then viewed the videos and read the transcripts repeatedly to discuss and formulate tentative assertions. In subsequent viewings and transcript readings, we compared our interpretations with the other author, and subsequently refined the transcriptions of information-seeking episodes to include other interaction factors including gestures, pauses, and overlaps of utterances. In cycles of interpretation of particular episodes and testing of categorical constructions of information seeking, we discarded, modified, or adopted emerging understandings.

During this process, the manuscript authors were blind to the motivational profiles of the students who were selected by another project member so that this knowledge would not bias their analyses.

Retrospective think-alouds and interviews. Interviews were conducted with students one-on-one with the second author about three weeks after the museum field trip, allowing sufficient time for the results from the video data to guide the interview structure. The interviews lasted about half an hour and were video recorded. The interview guide was semi-structured and contained three sections. First, the researcher asked students about their goals for the museum visit. Second, he showed two short video segments, less than one minute each, of the interviewee's behaviors at the heat pump game. After each video episode, the interviewer had students engage in retrospective think-aloud protocols [45] by asking the students to explain why they behaved as they did if they are able to recall those reasons. This method—also known as retrospective testing [46], post-task testing [47], and think after [48] —addresses the concerns that asking participants to verbalize their thoughts as they are engaging in a task may have a negative impact on their performance, disrupt their engagement, and change the way they would have done the task otherwise[49], [50].

To our knowledge, retrospective think-alouds with video recordings have not been used with high school students and in our context of a museum visit. However, similar video-recall procedures have been frequently used in family psychology research and were developed to elicit participants' subjective understanding of their interactions, behaviors, or experiences in conjunction with traditional observer coding systems [51]. Previous research has supported the validity of video-recall procedures by simultaneously recording a variety of physiological measures during the original conversation and again during the video-recall procedure. The physiological data during the recall session were significantly related to participants' physiological data during the original interaction, suggesting that individuals were "reliving" their experiences [52]. Further eyetracking studies have supported the validity and reliability of retrospective thinkalouds by analyzing the agreement between eye movements and the participants' retrospective recall of what they attended to in complete tasks [53].

The video segments used during the interview were flagged as ones that lacked sufficient details, based on our interaction analyses, to include or rule out as information-seeking behaviors. For example, in one simulated video recall episode, a student moved from his game to watch another student play the same game for about five seconds before returning to his game. There were no actions prior to or after that episode that provided details for identifying if he was seeking information and if so what information. There was no talk, as he simply went to the other side to watch when his game cycle ended and returned to his side to start a new game. When shown this video segment during the interview, the student indicated that he wanted to know the purpose of the physical handprints and if the other group had strategies for incorporating them into their gameplay. Because the other group also did not use the handprints, the student decided that they were not important and continued to not use them after returning to the game on his side. The supplementary data from the interview allowed us to document the clip as an information-seeking behavior and informed our typology of the different types of information seeking.

3. Findings

Research Question 1: What types of information-seeking behaviors do students employ while engaging with an educational game in a museum exhibit?

Our categorization of the types of information-seeking behaviors that students employed resulted in a typology that includes two dimensions: 1) social to non-social; and 2) more directed to less directed. The first dimension refers to the degree of interaction or lack thereof with another individual and the second refers to the level of agency and intention for acquiring knowledge that underlie the information-seeking behaviors. This typology emerged after the authors sorted the behaviors and proposed a variety of categories for consideration and discussion until one evolved to represent all information-seeking behaviors that were identified in our game yet also provided a framework that is general enough to be adapted to other game and museum environments. Examples of the different information-seeking behaviors that we found within the different combinations of the dimensions are in Table 1.

Within the *social to non-social dimension*, we categorized the behaviors into three buckets: a) two-way interactions; b) one-way interactions; and c) no interactions with another individual. We define two-way interactions as social information-seeking behaviors intended to elicit a response such as a question directed at a specific person or group (e.g., “do you know why these colors changed?”). One-way interactions include watching others interact to learn from their interaction but not actively engaging in the gameplay. No interactions is defined as non-social information-seeking behaviors that do not involve another person (e.g., reading text on the wall next to the game).

For the *more directed to less directed dimension*, we categorized the behaviors into three groups: a) creating opportunities to seek information; b) using immediate resources to seek specific information; and c) exploratory behaviors. We define more directed information-seeking behaviors as being purposeful and less directed information-seeking behaviors as those exhibited with little to no intention to act on the new information. The most directed part of that dimension is creating opportunities to seek information such as when a student found a museum staff to seek help to understand the scientific simulation. Moderately directed information seeking includes instances in which students used immediate resources to seek information such as taking advantage of the large, slanted screens to watch other students play to learn from their interactions. Finally at the less directed end of the continuum, we include exploratory behaviors such as asking “what is going on?” without being specific about the point of confusion.

Table 1. Typology for information-seeking behaviors.

		←Social		Non-Social →
		Two-way interaction	**One-way interaction**	**No interaction**
More Directed ↑	**Creating opportunities to seek information**	Finding and speaking with a museum educator to ask for an explanation about how the heat pump works	Changing one's location to track different conversations to selectively eavesdrop on ones that are relevant to the information being sought	Testing personal hypotheses of how a heat pump works through connecting the visual with different speeds and directions of cranking
	Using immediate resources to seek specific information	Asking the group why the colors in the scientific simulation changed while pointing to the heat pump chambers on the screen	Watching another student play to learn new techniques to apply them to the next cycle of the game	Reading the text on the exhibit walls and displaying an intention to use that information such as towards recording the iPod video
↓Less Directed	**Exploratory behaviors**	Asking "what is going on?" without being specific about the point of confusion	Watching another student play without displaying an intention to gain or apply specific knowledge	Reading the text on the exhibit walls without displaying an intention to gain or apply that knowledge

Research Question 2: How do game design features influence the way students engage with the game?

Our findings revealed insights related to four key design features that partially determined, constraind, and supported the types of needs and inquires that arose from the learner during their interaction with the exhibit. We adopt the term design feature from Ke [39] to reflect how content and learning were integrated into the gameplay design. These design features can both be integrated into the design of the game itself or pertain to the design of the space and spatial organization of the game. Therefore, our insights are most applicable to other learning environments that are game-based and/or large, informal spaces. Through providing a case study of the interactive network of social others, physical objects, and digital displays, we hope to provide examples that other designers and researchers can draw upon to better understand how their learners' goals may interact with design features of the learning environment to influence their information-seeking behaviors. In guiding that connection, we also conclude the section on each design features with broader insights that emerged from that analysis.

Design feature #1: Close proximity of games. The proximity of two identical back-to-back games at the heat pump exhibit *(Figure 4)* and the design of the players facing each other allows for players on opposite sides to hear each other's conversations and move between games. Individuals can therefore pursue their goals by weaving in and out of conversations that align and misalign with their goals. This is illustrated in an episode in Group A during which Amy and Ashley announced that they did not understand what was going on. Neil, who endorsed a predominantly mastery goal orientation, pointed to the scientific simulation of the heat pump in the middle of the screen to ask them what that visual conveyed. In response to his question, Ashley shrugged and Amy continued to turn the physical crank while laughing and not responding to his question. When shown this episode during the video-recall portion of the interview, Neil explained that he still did not know how the heat pump worked at this point and was therefore engaging in *more directed* and *social* information seeking by asking the other students to decipher the simulation with him.

Although Amy and Ashley did not engage in that conversation with him, another student from the other side popped her head around her game screen to answer. Mary, who endorsed a high mastery goal orientation similarly to Neil, chimed in with her three predictions about how the heat pump works by making references to the visual simulation as well as to the physical handprints. Neil then turned away from Amy and Ashley and engaged in a conversation with Mary. Although Neil's information-seeking behavior was unsuccessful when directed at Amy and Ashley, he received the help from Mary as a result of the close proximity of the two games.

Insight. The spatial arrangement of the objects in the learning environment has implications for the amount of opportunities that students get to find other classmates who are pursuing similar goals.

Design feature #2: Short, low-stakes game cycles. The heat pump exhibit's feature of a one-minute game that did not penalize multiple tries provided opportunities for students to learn through experimentation. For instance, at the outset of his gameplay, Frank cranked the heat pump clockwise very quickly while watching the simulation of the heat pump change accordingly. Then he cranked the heat pump counterclockwise very quickly. In the post-visit interview, a researcher showed Frank a clip of himself during these episodes in which his actions resulted in low game scores. Frank, who endorsed a high mastery goal orientation, explained his action by saying, "I really didn't know what was going on with the heat pump. I had some hypotheses that I came up with so it was a bit of guessing. My goal was trying to understand the heat pump and what it did." These goal-driven behaviors that aligned with the mastery goal orientation that Frank endorsed reflect a *more directed* and *non-social* information-seeking pattern that was supported by the design of the game. The low-stakes feature of the game allowed for Frank to experiment with his questions and to pursue a mastery goal of understanding the simulation, similarly to how classrooms that are led by teachers who encourage questions influence students to engage in adaptive help seeking with the goal of understanding how to do a problem rather than focusing on quickly getting the correct answer [22].

The short game cycle, however, also disrupted Frank's information seeking. In another instance, as his classmates played the back-to-back heat pump games, Frank stood to the side in the middle and did not participate in the discussions that were predominantly focused on performance-approach goals of high scores rather than mastery goals of science understanding. Classmates laughed and shouted directions at each other to crank left or right, faster or slower, to get the highest possible score. In the post-visit interview, Frank said that he felt the purpose of the museum visit was to learn and not to play. He chose to stay out of the discussions focused on high scores, but when he overheard the word "evaporation" being spoken, he joined the conversation and said, "I heard something about evaporation and…" However, he was interrupted by the results screen appearing and Amy exclaiming her score as Ashley asked her if she was going to try again to get a score of 100%.

Related to the short cycle, the start of a new game provides an opportunity for a natural switch in conversational topics, a design feature that can shift the goal of the group. For example, in Group A's interactions with the game, Amy and Ashley strategized to get a high score while Frank stood to the side of the game. The simulation of the scientific mechanism of the heat pump at the center of the screen was not a point of focus for Amy and Ashley, as indicated by them looking at the side temperature meters and shouting out the numbers. When the screen transitioned from the results screen to a new game screen, however, their conversation about scoring high points subsided and they were quiet. As the new game started, Frank walked from the side to the front of the game screen to join them and shifted the conversation towards one about scientific understanding rather than high scores:

Frank: How many degrees is it?

Amy: 19 there *((points to temperature meter on the left where the house is))* and it is 26 there *((points to the temperature meter on the right))*, no 23, 24, now it is almost as hot *((keeps her finger pointing at the temperature meter on the right as it changes))*

Frank: What is it that happens, really?

Amy: I have no idea.

Frank: What is that installation there? *((points to the simulation of the interior of the heat pump dynamically moving))*

Amy: It is cold there, isn't it?

Mary: ((walks from her side to the other side with Frank and Amy)) Here is heat pump. When this here gets colder, this needs to be warmer. ((puts one finger on the top and one finger on the bottom of the right blue chamber of the heat pump simulation))

The conversation between Frank, Amy, and Mary proceeded to be about understanding how the heat pump scientifically works for the remainder of the game cycle, taking on a mastery goal orientation rather than a performance-approach orientation.

Insight. The duration of an educational activity affects the ease in which students can switch the goals pursued by the group.

Insight. The low- or high-stakes nature of an educational activity affect the degree in which students can engage in quick, exploratory learning.

Design feature #3: Ease of seeing other players' screens. The screen for the heat pump game was large and slanted because it was designed to function as both an individual and a group activity during which several visitors surrounding the heat pump game could see the screen. At one point, Neil, who was predominantly mastery goal oriented, left his game screen and stood by the one on the other side to watch his classmates play. When shown this video clip and asked to explain what was going on during the post-visit interview, Neil said that he wanted to know if they had other strategies of playing the game and if they used the handprints in a helpful manner. This vicarious learning behavior of gaining knowledge from the gameplay of others is an example of a *one-way social interaction* and *directed* information seeking. Through this action, Neil said that he determined that the other team was not using the handprints either and decided that the prints did not have an important role.

The opportunity for vicarious learning was also used by Linda, of Group B, who endorsed a very different goal of a high performance-avoid orientation of not appearing incompetent in front of others. This achievement goal endorsement aligns with her behavior of opting to not play the game when others asked if she would like to participate and her explanation during the interview that she declined because she did not want to look stupid. This behavior aligns with her endorsement of a high performance-avoid orientation in her self report. Rather than participating by taking an active role in playing the game, she opted to learn through others' gameplay and their mistakes.

Insight. The size and arrangement of a screen has implications for the role of vicarious learning.

Design feature #4: Instructional aims. The instructions for the heat pump game oriented students to a goal of keeping the appropriate temperature in the house: *Use the heat pump to keep the house temperature at about eighteen degrees throughout the year*. Amy, Carly, and Mary were very fixated on the numbers and sought information on the easiest way to keep the house within the optimal temperature to score well in the game. Although Carly endorsed a moderate mastery goal orientation in conjunction with a high performance-approach orientation, in her interview, she said that since the goal of the game was to get a high score, she did not mind not understanding the science to get a high score given the context. As indicated by their behaviors and talk, those three students were able to recognize a pattern between the temperature meters on the side, calendar bar at the bottom, and crank directions that allowed them to get high scores without paying attention to the scientific simulation of the inner workings of the heat pump.

Towards the end of the heat pump exhibit visit, however, students were asked to make a video using an iPod that displayed another set of instructions: *Try the heat pump game. Describe what you see and feel. Take a short video and some pictures where you try to explain why the house gets warmer and colder despite temperature changes there*. These instructions were intended by the designers to guide students towards adopting a mastery goal of understanding how the heat pump works and making connections the crank direction, heat pump simulation screen, and handprints. After Carly read the iPod directions, these interactions followed:

George: I do not know why. It's just like that.
George: That's it?
Carly: Wait.
George: The heat pump is made to do it.

The act of needing to record a video prompted them to seek a deeper understanding of how the heat pump functions and to reflect on the various components of the game, resulting in *more directed, social* information seeking:

George: Wait a minute. I just have to think a bit about what to say first.

Carly: Say that when we cranked this ((pointing at the physical rank)).
George: Yes.
Carly: And tried to keep the inside temperature stable.
George: Yes.
Carly: We noticed according to season it was colder and then it was warmer.
George: And we had to adjust ourselves to the environment in order to get a stable temperature inside.
Carly: Yes.
Carly: Because, yes.
George: Yes.
Carly: Because since it gets so hot in the summer this *((pointing to inside the thermometer))* will be warmer but you try to make it colder. We need it to be cooler.

The students continue the discussion and read the text on the walls to develop their iPod video. These interactions show that even though students may endorse a particular goal at one point in the visit, these goals can be reshaped by the environment including through the wording of the instructions.

Insight. The framing of the goal of the task has implications for which parts of the learning objects students focus on and the content of the conversations that they have with their classmates.

Research Question 3: How does an understanding of achievement goals—and how they align or misalign with game features—improve the design for learner and player experiences?

Our findings illustrate the need for considering the achievement goal orientations that students endorse, either as a result of prior experience or a consequence of ways that chosen design features shape their goals, when designing educational activities. This understanding of goal pursuit is especially relevant in game-based approaches that inherently have consequences for both mastery and performance goal orientations. The case illustrations below show that students need to feel that they have control over obtaining their goals—goals that are often refined as part of their interactions with the learning environment. There is a need to keep in mind not only how design influences the construction of those goals but also the attainability of those goals.

Mastery goals do not always lead to adaptive outcomes. The two students in our study who reported high levels of mastery goal orientations for learning in science classrooms, *Frank and Neil*, reported that those goals extended to their school field visit to the science museum. This motivational profile to want to develop knowledge and understand is extremely adaptive, yet it was these types of students that the exhibit managed to disappoint. The museum exhibit was not designed to provide the resources that Frank and Neil needed to attain their goals of a deeper level of understanding the mechanisms that underlie how the heat pump works. The designers' intent of the heat pump game was to provide students with the general understanding that the heat pump, as a single device, is able to both heat up and cool down a house while using significantly less energy than other alternatives. The animation of the inner workings of the heat pump was intentionally designed to introduce students to the notion of energy transfer without overwhelming them with scientific details. The assumption was that students would enjoy the game as long as they were able to understand enough about the heat pump to perform well in the game and that the context of the heat pump would catch their attention and be relatable for their later opportunities to learn about energy transfer. Additionally, the animation could be used by a museum educator or teacher to further explain the mechanisms of the heat pump, but the lack of detailed explanations for every heat pump component and animation was not expected to be problematic.

Accordingly, during user testing sessions for the game, the focus was on leveling its difficulty to ensure that it was not too hard or too easy rather than ensuring that the game was appropriately scaffolded for the different levels of scientific knowledge that students may want to attain. It is worth nothing however that that issue may have not emerged from user testing even if the team had been more cognizant about evaluating it because those testing sessions were conducted in a university lab. As such, students like Frank and Neil may have not brought those mastery goals with them in that context in the same way they do when it is a school-related field trip. Regardless, our study shows that even in the more playful, informal setting of a museum, when it is in the context of a school field trip, there are students who are focused on deep learning and particularly want to understand the underlying science. It is concerning that the students who engaged in our game with a strong desire to learn showed a diminished intensity of mastery goal pursuits over time.

When asked what they would have changed to make the game better, Frank and Neil said they would have had better explanations for what is going on such as by more text in the game itself. This conflict could have been resolved in two ways. The first is to do as the students suggested and provide more details. There could be different layers of the game in which students can zoom in for more details so that the details would not overwhelm the students who do not want that level of detail at the moment. Furthermore, there could be two modes of the heat pump—one as the currently operating game and another as simply a simulation in which students can experiment and discuss and pause as needed. This would help with facilitating mastery-oriented conversations, which were frequently interrupted as a result of the short game cycle, as discussed earlier. A second option would be to not include extensive visuals in which students are not able to derive more sophisticated meaning. Perhaps the evaporation and boiling animations in the heat pump game or the changes in color within the chamber that prompted more questions than they answered could be removed. The intention was that such animations would spark students' interest to later learn more about those mechanisms, but in reality, the highly mastery oriented students expected to be able to resolve their confusion and develop that additional knowledge immediately. As such, the graphics could have been designed to not influence the construction of goals that are not attainable.

Performance-avoidance goals are not always damaging. Despite the robust findings in the achievement goal literature about the detrimental effects of performance-avoidance goals, we found that there are exceptions. As an example, we illustrate the interactions and thoughts of Linda, who adaptively aligned the environment's resources with her preference for both performance-avoidance and mastery goal orientations by vicariously participating. While watching a video of herself refusing to play, Linda explained during an interview that she declined when asked whether she wanted to try the heat pump game because she did not want others to see her get a low score. However, she vicariously participated with the aim to learn by watching her group interact with the game. The large, slanted screen at the heat pump game was adaptive for Linda's goal because it allowed for several visitors to simultaneously view the screen. This opportunity aligned with her high performance-avoidance orientation. Rather than participating by taking an active role in playing the game, she opted to learn through others' gameplay and their mistakes. Linda did, however, later try the game herself when no one was around. In her interview, she said she was thankful no one appeared because her score was not very high. Linda, who endorsed both high performance-avoid and high mastery goal orientations, made the two seemingly incompatible goal orientations work for her as she clearly exhibited performance-avoidance behaviors but could still find ways to focus on understanding the heat pump mechanisms.

Allowing Linda to exercise her goal preference, as this exhibit did, may have been more beneficial than designing in a way that is intended to shift her goal to another orientation. It is quite possible that she would have otherwise disengaged entirely because it difficult to change avoidance-based goals [34]. Those goals are framed in terms of the presence or absence of negative possibilities, which means that avoidance goal pursuit can only produce one of two outcomes: successful avoidance of a negative possibility, or failure to avoid a negative possibility. Neither of these outcomes is likely to provide the positive competence information needed to shift the individual's focus from a negative possibility to a positive possibility and, accordingly, to the adoption of an approach goal.

4. Discussion

Practical Implications

A helpful way of reflecting on the relations between design features and learners' motivations and goals is through the notions of inscription and translation. Broadly, inscriptions are the intentions behind the design of the game and translations are how the users actually perceive and use the game features. Latour [54] uses the term *inscription* to describe how researchers, designers, and curators inscribe certain features in the construction of the material environment in order to facilitate human action. For example, our team intended to include multiple areas of focus (e.g., scientific simulation, temperature meter, handprints) for learners to choose the resources that they decided most aligned with their goals. To assess how those intentions unfolded, we analyzed students' *translations* [54] of the design features to understand the processes through which they selected and used the material resources in ways that were relevant to their needs and goals. In our case, the competing features that were inscribed into the design affected the group dynamics as students in the same group pursued different goals, often causing frustration for the sole individual with a different goal who may be left out of the conversation. In some cases, students waited for opportunities to move out of one conversation that was a mismatch with their goal and into another that was more related to their goal. Being cognizant about the relation between inscriptions and translations would help designers and educators understand their misconceptions about how certain features of a learning environment are related to information-seeking patterns and goal regulation, allowing for that information to guide revisions of a current exhibit as well as future development.

Designing inscriptions thoughtful of learners goals. When designing learning environments, often the focus is on how to design in ways that allow for certain types of interactions to occur with the thought that those interactions lead to learning. However, there is another part to this equation: it is equally as important to consider that learners have different motivations and goals and will accordingly differ in how they perceive what the design affords and how they interact with the environment. Our study examined ways in which design affords different types of information-seeking behaviors while accounting for those behaviors being reciprocally influenced by perceptions that are colored by students' personal traits, such as their goals.

Information seeking behaviors as translations. By focusing on students who endorsed different types of goals for science learning, we were able to capture a variety of information-seeking behaviors. Much of the previous research on help seeking and information seeking have been conducted in the context of classrooms and internet searches, and categorizations from that work were not applicable our context. We derived a typology for the information-seeking behaviors that emerged at the science exhibit and categorized the observed behaviors along the two behavioral dimensions of: 1) social to non-social; and 2) more directed to less directed. We offer this typology as a means of uncovering and better understanding the types of translations of the material resources that comprises a museum space, such as instructions, games, physical organization, and so forth. We also believe this typology can inform future research on learners' engagement with games and at science museums as well as guide future research about adaptive and non-adaptive information-seeking behaviors and how to design for adaptive paths.

Using student translations to provide guidance for future design. Understanding the ways the inscribed features are translated by students allows for data-driven conversations about how one can redesign exhibits to be more thoughtful of students' information-seeking behaviors. For example, to address the insight from our analyses that short game cycles cutting off productive conversations, one could create two modes: one being the described timed game and the other being an untimed simulation for experimenting with the components of the heat pump and pausing, replaying, and creating opportunities to seek information and for social interaction such as discussing the animation in depth. In another case, one disadvantage of the ease of seeing other people's screens, based on our analyses, may be that educators may want students such as Linda to participate and learn more actively, rather than only vicariously, due to her fear of failure in front of others. The untimed simulation mode, therefore, may be a productive stepping stone for such students to become more comfortable with being involved because no scores are displayed. Finally, we found that students are able to get a high score by gaming the system. For example, Carly and George memorized which direction to turn the crank during the different months, illustrating that future versions of the exhibit need to better integrate the science learning with the game mechanics such that understanding the science would be a stronger contingency for receiving high scores.

Theoretical Implications

Our study extends the theoretical framework on achievement goal revision by using video data to continuously measure behavior and supplementing that with interviews to provide examples of how mastery goal orientations can diminish over time. Much of the work on Achievement Goal Theory shows consistent positive outcomes that result from mastery goal orientations such as better cognitive strategy use and greater persistence [10]. Work on the precursors of such orientations have focused on elements such as the classroom environment, the types of praise that students receive from parents, and peer influence (e.g., [15]). What has been sparse in this work, however, are the factors that influence not just the adoption of mastery goal orientations and the behaviors that they initiate but also the *maintenance* of mastery goal orientations over time [55].

With respect to goal revision,in light of the outcomes that students receive as they progress towards a goal, students may revise their expectancies for whether or not they can succeed based on changes in their perception of the stable, uncontrollable, and global nature of the outcomes [5], and in line with the attribution theory [56]. Much of the work on goal revision, however, has looked at performance goals. “Such expectancy revision, particularly downward revision, is most likely to occur with performance goals” because they are “fostered by and, in turn, foster views of ability as a stable, uncontrollable, global factor” [5]. Students may, for example, switch between performance-approach and performance-avoidance goals as a result of information about their level of competence. Mastery goals, however, they argue, are more likely to reflect ability being viewed as specific and acquirable and encourage more effort to attain goals.

What is missing from this view, however, is the acknowledgement that effort does not always pay off and does not always lead to progression towards goals for mastery-oriented students. The situated context can hinder the pursuit of mastery goal orientations when the resources available are not adequate for students to reach their learning goals or to gauge if they are progressing towards it. As illustrated in our study (Neil), it is not simply expectancy of one’s ability to learn and perform that matters but also one’s expectancy that the necessary resources to overcome obstacles are there. In the heat pump game, mastery goal pursuits were not successful because the resources did not help students’ progress towards mastering their understanding of how the heat pump works.

Our study shows that the mastery-oriented students employed great effort in learning the material and tried different strategies as they attempted to engage their peers in mastery-oriented conversations, experimented with the game, and participated in learning-related conversations. However, each interaction left them unsatisfied, and it is possible that their expectancies for the exhibit having the resources that they needed to attain their goals diminished. “Revision of expectancies plays a critical role in the maintenance or abandonment of achievement strivings [5]. For example, the tendency to exhibit too-rapid expectancy decreases in the face of obstacles appears to be a key factor in certain maladaptive achievement patterns.” As we have seen, technology and games provide a greater risk of producing “too-rapid expectancy decreases” given their quick interaction and feedback patterns, and in our heat pump game, this occurred. Focusing on goal attainment expectancies allows us to gain a deeper understanding of the ways in which students adjust their goal pursuits after setbacks.

Final remarks

Our study provided insight about the mismatch between designers' intentions behind various design features and the actual experiences of students. We hope that the insights that emerged from our analyses illustrate for researchers and designers how motivation theories provide a helpful lens for understanding the nuances of student engagement, and in particular, the relations between goals, design, and information-seeking behaviors. To our knowledge, this article provides the first step towards a framework that focuses on that system of interactions in game-based learning environments. In doing so, we used interaction analyses of videos and interviews to conduct second-by-second analyses at a small grain-sized level to build on what is largely survey-based reporting in the achievement goals research literature.

Given this new direction and the time-intensive method, our study findings are limited by its exploratory nature with a small sample size of four students. Though we intentionally chose them because they represented different motivational profiles, we likely would have seen other types of information-seeking behaviors had we analyzed more students or had we assessed contexts beyond the heat pump game. As such, our typology of information-seeking behaviors are preliminary as are our insights about the design features. We recommend that future research examines the network of interactions that we proposed *(Figure 3)* with other demographics of students in other contexts of educational games and museum exhibitions.

Findings from our work illustrate the need for considering students' goal orientations when designing educational exhibits, particularly for science. For example, the two students in our study who reported high levels of mastery goal orientations for learning in science classrooms reported that their goal extended to their visit at the science museum, which was part of a school field trip. This motivational profile to want to develop knowledge and understand is extremely adaptive, yet it was these types of students that the exhibit managed to disappoint.

Our case illustrations show that students need to feel that they have control over obtaining their goals—goals that are refined as part of their interactions with the learning environment. Though students may the exhibit with a pre-established general goal to learn and understand science, their specific goals are influenced by the context at play. To increase students' expectancy to be able to attain their goals, designers should attend to whether there are steps that learners can take towards their refined goals. This includes keeping in mind not only how design influences the construction of those goals but also the attainability of those goals.

Finally, as we detailed through our case study, a design feature is not inherently "good" or "bad" and can have both consequences. For example, the short, low-stakes game cycles were very conductive to experimenting and mastery-oriented learning. However, conceptual discussions about the display of the scientific simulation of the heat pump were hampered by the short cycles that transition away from the simulation display back to the start screen. Accordingly, this article is not prescriptive. It is our hope that others will be able to use our findings to extract ideas about how to account for learners' goals and motivation when choosing which design features to include in their educational products.

References

1. R. E. Clark, K. Yates, S. Early, and K. Moulton, "An analysis of the failure of electronic media and discovery-based learning: Evidence for the performance benefits of guided training methods," in *Handbook of Training and Improving Workplace Performance, Volume I Instructional Design and Training Delivery*, K. H. Silber and R. Foshay, Eds. Somerset, NJ: Wiley, 2010, pp. 263–297.
2. F. Ke, "A qualitative meta-analysis of computer games as learning tools," in *Handbook of Research on Effective Electronic Gaming in Education*, no. 1, R. E. Ferdig, Ed. 2009.
3. T. Sitzmann, "A meta‐analytic Examiation of the Instructional Effectiveness of Computer Based Simulation Games," *Personnel psychology*, vol. 64, no. 2, pp. 489–528, 2011.
4. P. Wouters, C. van Nimwegen, H. van Oostendorp, and E. D. van der Spek, "A meta-analysis of the cognitive and motivational effects of serious games.," *Journal of Educational Psychology*, vol. 105, no. 2, pp. 249–265, May 2013.
5. C. S. Dweck and E. L. Leggett, "A social-cognitive approach to motivation and personality.," *Psychological Review*, vol. 95, no. 2, pp. 256–273, Apr. 1988.
6. D. H. Schunk, P. R. Pintrich, and J. L. Meece, *Motivation in education: Theory, research, and applications*. Pearson Higher Ed., 2012.
7. J. Zhou and D. Urhahne, "Self-regulated learning in the museum: understanding the relationship of visitor's goals, learning strategies, and appraisals," *Scandinavian Journal of Educational Research*, Apr. 2016.
8. C. Heath and D. vom Lehn, "Configuring 'Interactivity' Enhancing Engagement in Science Centres and Museums," *Social Studies of Science*, vol. 38, no. 1, pp. 63–91, Feb. 2008.
9. S. Nicholson, "A RECIPE for Meaningful Gamification," in *Gamification in Education and Business*, no. 1, T. Reiners and L. C. Wood, Eds. Cham: Springer International Publishing, 2015, pp. 1–20.
10. E. M. Anderman and C. A. Wolters, "Goals, Values, and Affect: Influences on Student Motivation.," in *Handbook of educational psychology*, P. A. Alexander and P. H. Winne, Eds. Lawrence Erlbaum Associates Publishers, 2006, pp. 369–389.
11. A. M. Conley, "Patterns of motivation beliefs: Combining achievement goal and expectancy-value perspectives.," *Journal of Educational Psychology*, vol. 104, no. 1, pp. 32–47, Feb. 2012.
12. C. Senko and J. M. Harackiewicz, "Regulation of Achievement Goals: The Role of Competence Feedback.," *Journal of Educational Psychology*, vol. 97, no. 3, pp. 320–336, Aug. 2005.
13. P. R. Pintrich, "Multiple goals, multiple pathways: The role of goal orientation in learning and achievement.," *Journal of Educational Psychology*, vol. 92, no.

3, pp. 544–555, Sep. 2000.
14. K. E. Barron and J. M. Harackiewicz, “Achievement goals and optimal motivation: Testing multiple goal models.,” *Journal of Personality and Social Psychology*, vol. 80, no. 5, pp. 706–722, May 2001.
15. C. Ames, “Classrooms: Goals, structures, and student motivation.,” *Journal of Educational Psychology*, vol. 84, no. 3, pp. 261–271, Sep. 1992.
16. T. Urdan, “Predictors of Academic Self-Handicapping and Achievement: Examining Achievement Goals, Classroom Goal Structures, and Culture.,” *Journal of Educational Psychology*, vol. 96, no. 2, pp. 251–264, Jun. 2004.
17. F. Pajares, S. L. Britner, and G. Valiante, “Relation between Achievement Goals and Self-Beliefs of Middle School Students in Writing and Science,” *Contemporary Educational Psychology*, vol. 25, no. 4, pp. 406–422, Oct. 2000.
18. A. J. Elliot and M. A. Church, “A hierarchical model of approach and avoidance achievement motivation.,” *Journal of Personality and Social Psychology*, vol. 72, no. 1, pp. 218–232, Jan. 1997.
19. J. M. Harackiewicz, K. E. Barron, S. M. Carter, A. T. Lehto, and A. J. Elliot, “Predictors and consequences of achievement goals in the college classroom: Maintaining interest and making the grade.,” *Journal of Personality and Social Psychology*, vol. 73, no. 6, pp. 1284–1295, Dec. 1997.
20. A. C. Graesser, S. K. DMello, and A. C. Strain, “Emotions in Advanced Learning Technologies,” in *International Handbook of Emotions in Education*, International handbook of …, 2014.
21. K. Schenke, A. C. Lam, A. M. Conley, and S. A. Karabenick, “Adolescents' help seeking in mathematics classrooms: Relations between achievement and perceived classroom environmental influences over one school year,” *Contemporary Educational Psychology*, vol. 41, pp. 133–146, Apr. 2015.
22. S. A. Karabenick and R. Sharma, “Perceived teacher support of student questioning in the college classroom: Its relation to student characteristics and role in the classroom questioning process.,” *Journal of Educational Psychology*, vol. 86, no. 1, pp. 90–103, Mar. 1994.
23. R. S. Newman and M. T. Schwager, “Students' perceptions of the teacher and classmates in relation to reported help seeking in math class,” *The Elementary School Journal*, vol. 94, no. 1, pp. 3–17, 1993.
24. G. Marchionini, *Information Seeking in Electronic Environments*. Cambridge University Press, 1997.
25. J. Juul, *The Art of Failure*. MIT Press, 2013.
26. A. Bandura, *Social foundations of thought and action: A social cognitive theory.* Prentice-Hall, Inc, 1986.
27. G. P. Latham and E. A. Locke, “Self-regulation through goal setting,” *Organizational Behavior and Human Decision Processes*, vol. 50, no. 2, pp. 212–247, Dec. 1991.
28. J. Y. Shah, A. W. Kruglanski, and R. Friedman, “Goal systems theory: Integrating the cognitive and motivational aspects of self-regulation,” in *Motivated social perception The Ontario symposium*, S. Spencer, S. Fein, M Zanna, and J. Olson, Eds. Mahwah, NJ, 2003, pp. 247–275.
29. C. Wrosch, M. F. Scheier, G. E. Miller, R. Schulz, and C. S. Carver, “Adaptive Self-Regulation of Unattainable Goals: Goal Disengagement, Goal

Reengagement, and Subjective Well-Being," *Pers Soc Psychol Bull*, vol. 29, no. 12, pp. 1494–1508, Dec. 2003.

30. B. J. Zimmerman, "A social cognitive view of self-regulated academic learning.," *Journal of Educational Psychology*, vol. 81, no. 3, pp. 329–339, Sep. 1989.
31. M. Bong, "Within-grade changes in Korean girls' motivation and perceptions of the learning environment across domains and achievement levels.," *Journal of Educational Psychology*, vol. 97, no. 4, pp. 656–672, Nov. 2005.
32. E. M. Anderman and C. Midgley, "Changes in Achievement Goal Orientations, Perceived Academic Competence, and Grades across the Transition to Middle-Level Schools," *Contemporary Educational Psychology*, vol. 22, no. 3, pp. 269–298, Jul. 1997.
33. L. H. Anderman and E. M. Anderman, "Social Predictors of Changes in Students' Achievement Goal Orientations," *Contemporary Educational Psychology*, vol. 24, no. 1, pp. 21–37, Jan. 1999.
34. J. W. Fryer and A. J. Elliot, "Stability and change in achievement goals.," *Journal of Educational Psychology*, vol. 99, no. 4, pp. 700–714, Nov. 2007.
35. M. L. Bernacki, V. Aleven, and T. J. Nokes-Malach, "Stability and change in adolescents' task-specific achievement goals and implications for learning mathematics with intelligent tutors," *Computers in Human Behavior*, vol. 37, pp. 73–80, Aug. 2014.
36. B. J. Zimmerman, "Motivational Sources and Outcomes of Self-Regulated learning and Performance," in *Handbook of Self-Regulation of Learning and Performance*, 2011.
37. A. Jornet and C. F. Jahreie, "Designing for Hybrid Learning Environments in a Science Museum: Inter-professional Conceptualisations of Space," in *Understanding Learning in Virtual Worlds*, no. 3, M. Childs and A. Peachey, Eds. Springer London, 2013, pp. 41–63.
38. "St.mld. 22: Motivasjon—mestring— muligheter [Motivation, requirement, possibilities]," Norwegian Ministry of Education and Research, 2011.
39. F. Ke, "Designing and integrating purposeful learning in game play: a systematic review," *Educational Technology Research and Development*, vol. 64, no. 2, pp. 219–244, Dec. 2015.
40. A. J. Elliot and H. A. McGregor, "A 2 × 2 achievement goal framework.," *Journal of Personality and Social Psychology*, vol. 80, no. 3, pp. 501–519, Mar. 2001.
41. G. Bjørnebekk and Å. Diseth, "Approach and avoidance temperaments and achievement goals among children," *Personality and Individual Differences*, vol. 49, no. 8, pp. 938–943, Dec. 2010.
42. B. Jordan and A. Henderson, "Interaction Analysis: Foundation and Practice," *Journal of the Learning Sciences*, vol. 4, no. 1, pp. 39–103, 1995.
43. J. A. Fredricks and W. McColskey, "The Measurement of Student Engagement: A Comparative Analysis of Various Methods and Student Self-report Instruments," in *Handbook of Research on Student Engagement*, no. 37, Boston, MA: Springer US, 2012, pp. 763–782.
44. Suchman L, *Plans and situated actions. The problem of human machine communication*. Cambridge University Press, 1987.

45. Jenny Preece, H Sharp, and Y. Rogers, *Interaction Design: Beyond Human-Computer Interaction*. John Wiley, 2015.
46. J. Nilesen, *Usability Engineering*. New York: AP Professional, 1993.
47. R. Teague, K. De Jesus, and M. N. Ueno, *Concurrent vs. post-task usability test ratings*. New York, New York, USA: ACM, 2001, pp. 289–290.
48. J. L. Branch, "Investigating the Information-Seeking Processes of Adolescents," *Library & Information Science Research*, vol. 22, no. 4, pp. 371–392, Nov. 2000.
49. P. Jennifer, R. Yvonne, and S. Helen, *Interaction design: beyond humancomputer interaction*. NY: Wiley, 2002.
50. J. E. Russo, E. J. Johnson, and D. L. Stephens, "The validity of verbal protocols," *Memory & Cognition*, vol. 17, no. 6, pp. 759–769, 1989.
51. D. P. Welsh and J. W. Dickson, "Video-Recall Procedures for Examining Subjective Understanding in Observational Data.," *Journal of Family Psychology*, vol. 19, no. 1, pp. 62–71, Mar. 2005.
52. J. Gottman and R. Levenson, "Physiological and Affective Predictors of Change in Relationships Satisfaction," *Journal of Personality and Social Psychology*, vol. 49, no. 1, pp. 85–94, 1985.
53. Z. Guan, S. Lee, E. Cuddihy, and J. Ramey, *The validity of the stimulated retrospective think-aloud method as measured by eye tracking*. New York, New York, USA: ACM, 2006, pp. 1253–1262.
54. B. Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford, 2005.
55. C. Senko and C. S. Hulleman, "The role of goal attainment expectancies in achievement goal pursuit.," *Journal of Educational Psychology*, vol. 105, no. 2, pp. 504–521, May 2013.
56. B. Weiner, "Attribution Theory, Achievement Motivation, and the Educational Process," *Review of Educational Research*, vol. 42, no. 2, p. 203, 1972.