Enhancing informal learning experiences with affect-aware technologies

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Abstract
Although institutions of informal learning, such as museums, science centers, and zoos, seek to convey knowledge, they also seek to influence visitors’ interest, attitudes, and feelings about the topics they address. Upon entering an informal learning environment, visitors are surrounded by choices: they decide what to see, where to invest their time, and how long to stay. The quality of the experiences depends on many factors, including the content and design of the exhibits, the ability of exhibits to promote sustained engagement, and the nature of the conversations visitors have with each other and staff. To succeed, it is critical that visitors have meaningful experiences that simultaneously have educational value. In this chapter, we discuss the role of emotions during informal learning experiences and discuss how affect-aware technologies could be used to enhance cognitive and affective outcomes. Four potential application areas are presented for the use of affect- and user-sensing technologies: (1) automation of evaluation tasks for informal learning, (2) to spark visitor interest and magnify the attracting power of exhibits, (3) to deepen engagement during learning activities, and (4) to promote productive conversational behaviors in groups as well as single visitors (with virtual agents). Key challenges for the future include the development of robust detection algorithms for noisy environments like museums, addressing privacy concerns, tracking visitors beyond single exhibits, and integrating heterogeneous sources of information into useful estimates of visitors’ knowledge, emotions, and goals.

Keywords: informal learning environments, free-choice learning, affect detection, engagement, learning sciences, adaptive learning technologies

1. Introduction
It is now widely acknowledged that learning is an emotional process. In schools or workplace training programs, those emotions often emerge in pursuit of goals put in place by some outside authority, such as a teacher or certification program. Further, attainment of such goals is usually dependent on performance on tests or other quantifiable measures of competence. In a way, students are almost “captive” to these goals both in the sense they are assigned and in whether they are achieved. In the language of motivation, learners are set up to pursue extrinsic rewards which position learning as a means to the end of receiving a good grade or earning a piece of paper declaring achievement. A majority of research on the role of emotions in learning occurs in formal contexts like these, where emotions are emergent and the unspoken goal of the educator (or software) is to “minimize the pain” associated with learning.
Of course, learning does not just occur in formal settings and the motivations for learning vary greatly. In reality, we learn continuously throughout our lives: it is estimated that through the age of 17, we spend only 18.5% of our waking hours in school (Bell, Lewenstein, Shouse, & Feder, 2009, pp. 28-29). Although time spent in formal learning environments drops dramatically after this, the idea that learning is somehow reserved for schools is outdated. Indeed, studies on brain plasticity and cognitive aging confirm that it is beneficial, and even pleasurable, to engage in intellectual activities throughout life, gain new skills, and pursue continuous personal growth (Greenwood, 2007; Hultsch, Hertzog, Small, & Dixon, 1999).

Modern theories of learning are beginning to incorporate these more nuanced perspectives on learning. One such characterization includes (1) “implicit” processes in the brain (normally outside of our conscious awareness), (2) formal learning experiences, and (3) informal learning experiences (Bransford et al., 2006). Furthermore, thinking and learning are no longer assumed to be solely cognitive activities. Deep links have been uncovered between emotions and cognition, reasoning, and decision-making, in general (Blanchette & Richards, 2009), so it is unsurprising that emotions have also been shown to play key roles in both the acquisition of new knowledge and in peoples’ ability to manage their own learning (Calvo & D’Mello, 2011).

This chapter considers the role emotions play in informal learning environments such as museums, science centers, and zoos. These institutions of learning are designed to promote understanding, conversation, and positive attitudes about their content. Importantly, choice plays a key role in all phases of the experience: visitors decide what to see, when to engage, and how long to stay. Emotions play a key role in each of these decisions, and so the best activities tend to take emotional factors into consideration. Because of these choices, learners tend to have more opportunities for self-directed learning than they are used to in formal settings. This means if an experience is not judged to be of value or sufficiently interesting, learners will simply disengage or seek other activities. There are no inherent consequences for this choice as there are in formal learning situations (e.g., a poor grade). Thus, creating and maintaining learner engagement is therefore fundamental to the success of designed learning spaces. The purpose of this chapter is to explore the application of user sensing and affect-aware technologies to promote engagement and, more generally, increase the power of designed learning spaces to achieve their goals. Of course, to do this well it is important to understand the role of emotions in informal learning, how it differs from other learning contexts, and how this understanding can be leveraged in principled ways.

2. The emotional and social contexts of informal learning
Visitors who walk into museums, science centers, and zoos are instantly thrust into a position of choice. They have to first decide how to navigate – should they be spontaneous and impulsive?

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1 Although many informal learning institutions support formal learning goals, such as offering field trips and special lectures for groups of students, the most common category of use is that of a small group, like a family, visiting during open hours and self-navigating their way through the space. This use case is the focus of this chapter.

2 We will refer only to “museums” from here on, but note that the implication is to include all open, designed informal learning spaces.
Or should they get a map and systematically work through the space? Once on their way, more decisions await: when to stop, how long to stay, and when to say something (if they are in a group or talk to themselves). On top of all of this, the decisions are usually negotiated with friends and family, who may or may not share common preferences. Of course, these decisions are not necessarily consciously deliberated and part of the charm of informal learning is precisely this prominent positioning of choice (Falk & Dierking, 2002). In this section, we discuss the context of these choices by briefly describing the motivations for museum visits, what is involved in “free choice” learning, and typical desired outcomes for informal science learning.

2.1 Why do people go to museums?
Falk and Dierking (2000) posit that humans are fundamentally seekers and makers of meaning. They refer to a “knowledge-thirsty public” and point out that in 1970, only 1 in 10 Americans visited museums regularly while in 2000, that number increased to between 5 or 6 (p. 2). To understand the cognitive and emotional processes involved in informal learning activities, it is first important to know why people choose to pursue them. To answer this question, Moussouri conducted a large-scale study of museum visitors asking them for the reasons behind their visit (1997). Perhaps unsurprisingly, visitors gave a wide range of responses:

- Many cited educational and entertainment goals, such as a desire to learn or have an enjoyable day.
- Many referred to social desires, such as to be with friends, children, and family.
- Some suggested it was because of the “place”; to be the kind of person who goes to museums.
- Finally, some gave practical reasons (e.g., “it was raining that day” or “the location was convenient”).

Other researchers have suggested that social motivations seem to be the primary force behind the decision to visit a museum. Perry (2012) summarizes by saying “for the most part, museum visits seem to be driven by a social agenda” and qualifies by adding that learning is “a highly valued characteristic of museum settings.” The observation that museum experiences are simultaneously social and educational is critical for the design of effective learning experiences. Tension does not need to exist between these goals: it is best to view the shared goals of learning (by visitors to the museum) as a vehicle for allowing achievement of social goals.

2.2 Free-choice learning
*Free-choice learning* is a broad term that positions the learner firmly in the center of their own educational choices. Falk and Dierking (2002) suggest that free-choice learning by definition “involves a strong measure of choice – choice over what, why, where, when, and how we will learn”. They go on to describe it as “self-directed, voluntary, and guided by individual needs and interests” (Falk & Dierking, 2002, p. 9). In its full sense, free-choice describes learning decisions made throughout life, such as how to use the internet, which books to read, what television shows to watch, what to visit when vacationing, and so on.
The power of free-choice learning is that it leads to *intrinsic motivation* activities. These are activities that people find inherently interesting or beneficial, and engage in for no reason other than the activity itself (Deci & Ryan, 1985). *Extrinsic motivation*, on the other hand, requires an external source of the motivation to engage, such as a grade or financial reward. Whether or not an activity is deemed intrinsically motivating is entirely determined by the person doing the activity, but the provision of choice, as well as the context of a learner having made a choice, has been found to dramatically increase intrinsic motivation as well as learning (Cordova & Lepper, 1996).

An overarching goal for informal learning institutions, therefore, is to provide experiences that have value in and of themselves – visitors should choose to engage in learning activities because they find them inherently satisfying. The emotions a visitor experiences during learning have a profound impact on whether or not such satisfaction is achieved. Clearly, free-choice learning is a concept that is ubiquitous in our lives and reflects the affordances of modern technologies such as easy internet access and the widespread use of mobile technologies. While the focus of this chapter is on designed spaces for informal learning, it is nonetheless valuable to consider this broader context and speculate that positive experiences in designed spaces might translate to more general habits associated with lifelong learning.

### 2.3 Desired outcomes for informal science education

What should people take away from a visit to a museum? How do we want the experience to change them? While formal learning environments typically focus on knowledge gains as the most important outcome, informal learning often seeks broader impacts. The National Science Foundation (NSF) in the United States, for example, requires funded projects to apply a framework for evaluating informal science education technologies that incorporates affective dimensions as well as knowledge (Friedman, 2008). Specifically, NSF proposes five categories: *awareness, knowledge, or understanding, engagement or interest, attitude, behavior,* and *skills* (see table 1).

<table>
<thead>
<tr>
<th>impact category</th>
<th>description</th>
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<tbody>
<tr>
<td>awareness, knowledge, or understanding</td>
<td>What a participant in an informal science learning activity consciously knows, whether it is during, immediately after, or long after the experience.</td>
</tr>
<tr>
<td>engagement or interest</td>
<td>How an experience impacts a participant in terms of excitement for a topic or involvement in the (or a related) activity.</td>
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<tr>
<td>attitude</td>
<td>Captures long-term changes in perspective of a participant as they relate to a topic, group of people, theories, or careers. Projects may strive to help participants formulate attitudes (where none existed) or adjust existing attitudes.</td>
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<tr>
<td>behavior</td>
<td>Encompasses the choices and actions of participants over time, and often relates to everyday activities. Many projects that focus on behavior focus on environmental or health concerns.</td>
</tr>
<tr>
<td>skills</td>
<td>Focuses on the procedural aspects of knowledge, such as engaging in scientific inquiry, problem solving, or acting creatively.</td>
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Projects are required to articulate desired impacts of a program, such as an exhibit or after school activity, and align them with these categories. For example, an exhibit on the respiratory system may have the knowledge/understanding goal to teach visitors that oxygen is absorbed by the lungs while carbon dioxide is expelled. In addition, it might seek a behavioral impact to reduce the occurrence of smoking in the life of a visitor. Museums and science centers also often seek to provide “sparks” for young learners – to inspire them to pursue careers in Science, Technology, Engineering, and Math (STEM). For NSF, a long-term mission is to increase the number of college students who pursue STEM degrees as well as the number of people entering the workforce with competency in STEM-related skills (National Research Council, 2011).

Of course, changing attitudes or behavior is an extremely tall order, especially for museum exhibitions. The typical “holding time” for an exhibit is exceedingly brief by formal learning standards: visitors are generally expected to spend less than four minutes at an exhibit (Falk & Dierking, 2000).³ To make it even more complicated, a phenomenon known as “museum fatigue” settles in after about 30 minutes of deep engagement with exhibits (Davey, 2005; Falk, Koran, Dierking, & Dreblow, 1985). Visitors are said to “cruise” after this initial – and very precious – period of engagement, severely reducing further opportunities to have any long term impacts.

So, the windows of opportunity are brief and informal learning spaces need to be carefully designed to achieve their goals. Ultimately, solving societal problems such as interest in STEM and changing attitudes about important topics, for example, transcends any single exhibition or informal learning opportunity. Although the burden is not assumed to be entirely on informal learning, it is widely regarded as a critical part of solving national challenges related to education. What is most important for the purposes of this chapter is the observation is that when designed informal experiences seek to influence a visitor’s attitude or behavior, affective concerns gain a heightened level of importance.

3 Designing and building engaging informal learning exhibits
Like any instructional design activity, it is important to design informal learning experiences, such as those available at museums, based on sound principles of learning and engagement. This section briefly summarizes the context of museum learning and discusses what it means to be engaged in a learning activity.

3.1 A simple model of learning in designed spaces
Informal learning educators have embraced the notion that visitors to museums are not to be treated as “receivers” of knowledge, but rather as active and engaged learners who construct their own knowledge. A substantial amount of research has been devoted to developing models of informal learning as well as identifying design principles that promote this constructivist view

³ Holding times vary dramatically, of course, based on the nature of the exhibition as well as a long list of contextual variables, such as the social situation, motivation for being in the museum, and so on. The take away message is that informal science educators who design for unguided, free exploration (the most common form of a visit) think in terms of seconds and minutes rather than tens of minutes or hours.
of learning (Falk & Dierking, 2000; Perry, 2012). For example, an established approach for reducing early disengagement from an interactive exhibit is to design for *immediate apprehendability*. This principle states that exhibits should use simple interfaces, leverage familiar ideas and controls, and give immediate feedback that allows visitors to self-monitor and observe changes (Allen, 2007). Deterring frustration, especially when it is due to a lack of usability, is essential as a visitor is making a judgment about the exhibit’s potential value.

As mentioned earlier, visitors are confronted with choices throughout their informal learning experience in a museum. To frame the discussion below, we consider a simplified model of a typical visit to a museum. The model includes three basic phases:

1. *Arrival*: the moment a visitor enters (or re-enters) a space that has multiple learning choices available to them. This can be a specialized area of a museum (e.g., that focuses on a specific discipline or topic), or the entire space.

2. *Navigation*: when the visitor walks around the space (either impulsively or systematically), evaluating the potential value of exhibits and making “stop” decisions. A stop is likely the result of an underlying curiosity, or some other “hook”.

3. *Experience*: after a visitor has decided to engage an exhibit, the visitor is in the driver’s seat to have the intended learning experience. Typically, designers hope that visitors stay engaged long enough to achieve the intended outcome and feel satisfied. It is considered a lost opportunity if the visitor leaves abruptly.

Upon deciding to disengage from a specific exhibit, the visitor loops back to make the next choice about what to do next. This outer loop can end for any number reasons, such as having explored the full space, boredom, or social pressures to leave.

![Figure 1. A simple model of unguided navigation behavior in museums. The visitor identifies Exhibit E, navigates to it, engages with it, then returns to the space to decide on the next activity.](image-url)
Missing from this very simplified model are the social elements of the experience, but they are critical. For example, a decision to stop is often due to someone else in a party stopping or asking to stop. Furthermore, exhibits are rarely designed for a single visitor (despite the situation shown in figure 1) - it is precisely the social interactions that are often responsible for much of the learning that occurs (Leinhardt & Knutson, 2004). User-sensing and affect-aware technologies have the potential to dramatically improve the quality of these conversations, and so we return to this notion later.

3.2 What does it mean to be engaged?
The idea of being engaged in or achieving engagement can apply at a number of levels. Broadly, it can be used to indicate interest, or simply a desire to know more about a topic. In terms of outcomes, NSF states that impacts in the engagement category should seek to “capture the excitement and involvement of participants in a topic, area, or aspect of STEM” (Friedman, 2008, p. 22). An example of an indicator for an engagement outcome is whether or not a visitor pursues additional information related to their experience at a later time. Another window into understanding visitor engagement is to analyze their timing and movement patterns, especially between variable layouts and designs for the same content (Yalowitz & Bronnenkant, 2009). Although these are certainly important indicators, for the purposes of this chapter, we drill down into the more moment-to-moment aspects of engagement. Although increasing holding time is not universally ideal, we adopt the goal of maximizing the educational quality of the several minutes of time that is available during a single exhibit visit. If that also translates into extending the stay time, it is difficult to view this as a bad outcome for an individual or small group, at least.

Engagement in an activity can be unpacked in a number of ways depending on the nature, context, and goals of the activity. In a multidisciplinary review of empirical studies about the concept, O’Brien and Toms (2008) propose that engagement consists of four distinct stages: (1) the point of engagement, (2) sustained engagement, (3) disengagement, and (4) reengagement. With respect to learning, education researchers often draw a distinction between three different categories of engagement, although the specific meanings vary between communities and are not widely agreed upon4 (Christenson, Reschly, & Wylie, 2012; Fredricks, Blumenfeld, & Paris, 2004):

1. **behavioral**: deep and meaningful involvement in learning activities, such as persistence, concentration, question-asking, and making contributions.
2. **emotional**: marked by learners’ “affective reactions to the activity, such as interest, boredom, happiness, sadness, and anxiety” (Fredricks, et al., 2004, p. 63)
3. **cognitive**: deliberate use of cognitive resources, such as memory and reasoning skills (e.g., problem solving); also includes use of self-regulated learning strategies.

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4 Because of the goals of the chapter, these definitions focus again on the fine-grained aspects of engagement and draw from the cognitive psychological perspective. In other academic circles, behavioral engagement has also been characterized as a willingness to follow rules, for example.
It is worth noting that other researchers have articulated more precise categories that account for additional factors such as motivation and social behaviors (Pekrun & Linnenbrink-Garcia, 2012). Related to these, the notion of conversational engagement refers to the depth and quality of interactions between visitors and museum staff (Leinhardt & Knutson, 2004). For informal learning contexts, the general aim is to promote on-topic conversations that suggest the co-construction of knowledge and enjoyment of the experience.

An elaborate investigation into engagement was conducted in the early 2000’s at the Exploratorium in San Francisco, CA. The resulting model, known as Active Prolonged Engagement (APE), sought to balance the needs of providing visitor-driven, open-ended experiences with the goal of conveying knowledge and understanding about STEM topics (Humphrey, Gutwill, & Exploratorium APE Team, 2005). They sought to position visitors as participants rather than recipients, for them ask and answer their own questions, and to stay actively engaged for longer periods of time. Although holding time is not widely agreed upon as a conclusive measure of engagement, studies conducted by the APE team found it to be correlated with other measures of learning (p.9). Based on hundreds of hours of recordings of visitors and interview data and with a wide variety of different designs, the team found that people would leave APE exhibits because of external factors (such as others in their group wanting to go) rather than thinking they had reached the “end”.

Thus, APE exhibits that were mostly open-ended, with no obvious stopping point, were the most effective. In a related finding, the provision of a variety of actions at every point – rather than an experience “on rails” – led to deeper engagement. Giving the visitor primary control over an informal learning experience is a key part of the APE formula. APE principles also encompass groups and social interactions. Exhibits that offered multiple interaction stations that allowed visitors to simultaneously use an exhibit, perhaps to pursue a common objective, produced higher levels of conversational engagement and interaction.

A great deal of design knowledge has accumulated about how to design effective and engaging exhibits. Visits to museums have steadily increased over the last several decades, and so research must continue to focus on efficacy and design. In the remaining sections, we outline one possible contributor to this goal by discussing the possibility of adaptive exhibits: those that can sense and change based on what it is detected or known about visitors. The idea of personalized education is a widely-recognized grand challenge (Woolf, 2010), and there are many reasons to include informal learning in the conversation.

4 Adaptive learning environments and user sensing technologies
According to Shute and Zapata-Rivera, “Adaptive educational systems monitor important learner characteristics and make appropriate adjustments to the instructional milieu to support and enhance learning (2012, p. 7). The assumption is that not all learners are the same and that learning experiences should be designed with learners’ needs and progress in mind. They propose a four-phase model (p.9):
1. **capture**: gathering input about the learner, whether it be cognitive (about problems being solved, for example) or physical (such as from user sensing).

2. **analyze**: inferring estimates of the learner’s knowledge, emotions, motivations, and so on. This step involves the maintenance of a learner model.

3. **select**: choose information that is best for a learner given the system’s current estimate of their knowledge, emotions, etc.

4. **present**: convey the selected content to the learner using available and appropriate technologies.

Although much of the work on adaptive educational systems has focused on the goals of formal learning, there is promise to generalize and extend the approaches to informal contexts. Hardware and software approaches now exists to reliably identify human forms, track movement, and classify emotional states (see section 2 of this handbook). For example, the depth-sensing Kinect camera, built by PrimeSense and marketed by Microsoft, changed the nature of home video consoles by allowing video game players to use their own bodies as the controller. Newer generations of the camera will have enhanced capabilities for facial recognition, eye tracking, and even estimating one’s heart rate.

User sensing technologies that are most suitable for use in museums are those that can be used unobtrusively and that require no action on the part of visitors. Privacy concerns are non-trivial and use of such technologies present significant societal challenges for us all. It may very well be that museums choose to not adopt such technologies based on these concerns (although they have been around for decades in the form of security cameras). In this discussion, however, we focus on affective dimensions that are detectable by technologies such as vision (e.g., cameras), sound (e.g., microphones), location tracking (e.g., GPS, RFID), and built-in physiological sensors (e.g., pressure grips, posture detectors). Although museums are often noisy and active environments, we assume that enough meaningful detection of emotions is still possible. More importantly, if exhibits were able to *adaptively* present information based on estimates of the visitor’s emotions, or even better, adjust the complexity or behavior of an exhibit’s function, it is likely that more visitors would have engaging and powerful experiences.

The application of adaptive learning technologies for designed spaces is a relatively recent development. For example, if someone’s “visiting style” can be inferred, it is possible to present information in more digestible ways for them (Antoniou & Lepouras, 2010). The next step is to seek to automate these learner modeling tasks and adaptation approaches. Our first example application area in the next section focuses on using only the inputs of user sensing hardware (for evaluation purposes), but the following three explore the idea of exhibits that adapt, predict, and seek to create more meaningful informal learning experiences for visitors.

**5 Some opportunities to enhance informal learning**

Although many museums have embraced advanced learning technologies, especially to increase the overall level of interactivity of their exhibits, only a few projects have sought to directly personalize learning experiences based on visitor behaviors. Researchers in Germany, for
example, showed that adaptive presentation of information on a mobile device (used to track the location of visitors) led to increased awareness of learning goals and produced corresponding gains in knowledge (Mayr, Zahn, & Hesse, 2007). Similarly, researchers at the Exploratorium in San Francisco, CA used RFID tracking technology to provide personalized content via the web (for viewing later) based on visitor exhibit visiting patterns (Hsi & Fait, 2005). These examples provide an important foundation for the idea of adaptive exhibits. So how might affect-aware technologies help solve the same kinds of informal learning challenges? How could exhibits enhance engagement when provided input about visitor emotional states? This section explores several possible uses of affect-detection technologies for informal learning that, quite plausibly, could be implemented with today’s hardware and automatic classification techniques.

5.1 Application area 1: Automating evaluations
The first and most straightforward use of user- and affect-sensing technologies involves the automation of activities normally performed by evaluators. For example, to capture holding times, evaluators normally stand off to the side and manually record arrival and departure times for individuals and groups at an exhibit, as well as a host of behavioral information like buttons pressed, signs read, and so on. It is relatively straightforward to use depth-sensing cameras to automate the detection of the arrival and departure of visitors, their number, and general demographic information (e.g., child, young teen, adult). A number of researchers have explored the use of video recordings to automatically supply such data (Ross & Lukas, 2005). With a live connection, this information could even be made available on a real-time basis for essentially all museum visitors and all exhibits equipped with a camera.

More interestingly, though, recent advances in affect detection could provide a far more detailed, real-time analysis of visitor behaviors. For example, head-tracking algorithms are now robust enough to reliably identify behaviors like nodding, smiling, and gaze direction (Morency, Sidner, Lee, & Darrell, 2005), which could all be mapped into outcome categories. Nodding and smiling, for example, would indicate agreement, understanding, and generally positive emotions. On the other hand, frustration, frowning, and head-shaking would suggest the opposite (at least in the United States). Such data would help evaluators track the general impact of exhibits over time and across categories, and it wouldn’t require a human to be present during any of the data collection. For the day-to-day operation of a museum, a sudden change in the emotions associated with an exhibit might suggest that something has gone wrong, like a missing or broken component. It is important to note that even if the sensing technology failed from time to time because of changes in lighting or occlusion, for example, the large amount of available and accurate data would still likely have some use.

It is easy to imagine other uses for evaluation using the other available technologies. Microphones could be used to detect conversations, even if the words cannot be fully recognized. Detecting meaningful conversations would be a taller order, but perhaps still not out of the question by identifying keywords related to the exhibit and other words related to process, cause-effect, and other sense-making clue words (i.e., deep natural language understanding would not
be needed to detect explanatory evidence in conversations). Of course, emotional cues would also be detectable from speech patterns, such as frustration, anger, or excitement. When combined with visual cues, the models could be made more precise. Beyond speech and vision, if an exhibit used buttons, joysticks, or chairs, they could be equipped with pressure sensors that could inform evaluators about how “rough” people are being or how engaged they may be based on their physical position and posture (D'Mello & Graesser, 2009).

Clearly, there are weaknesses with automated detection of visitor behaviors and emotions, but the technologies and approaches are robust enough to begin to ease the burden of evaluation for evaluation professionals (which is substantial). Further, there are many shared goals for evaluators and systems that track engagement, as we will see in application area 3, sustained engagement.

5.2 Application area 2: Sparking interest and acquiring the visitor’s attention

Upon approaching an exhibit, the first few seconds are critical to whether the visitor decides to invest their time and engage more deeply. As mentioned, design principles such as immediate comprehensibility (Allen, 2007) and the provision of simple and direct instructions (Perry, 2012) can make a substantial difference during this initial engagement (see figure 1). Visitors make rapid judgments of the potential value of exhibits – they quickly assess the look, usability, and content of exhibits to decide if they should invest more effort. The incoming state and properties of the visitor (or visitors) likely play a big role in predicting their choice to engage or not (Falk, et al., 1985). The key research question, then, is how might the initial presentation of content or appearance of the exhibit be adapted based on initial assessments of detected visitors’ emotional (or other) states?

The select phase of an adaptive system is responsible for how to provide initial instruction (Shute & Zapata-Rivera, 2012). Of course, that decision can draw from any number of dimensions resolved during the brief capture and analyze phases. For example, if the exhibit addresses a topic of less inherent interest to a particular visitor, there is likely a lower threshold for disengagement. In this case, it may make sense to present a narrative or emotionally compelling example in an effort to appeal to his or her emotions and stir up interest. Alternatively, it may be best for the exhibit to focus on providing a quick hook in the form of a surprising scientific fact or demonstration. The space of possibilities are obviously constrained by the exhibit itself, but a simple LCD could provide a wide range of possibilities, such as short videos, display of different text and images, or even a helpful pedagogical agent to activate social obligations. On the other hand, for visitors who display a high initial interest or curiosity (e.g., smiling, leaning forward, or concentration), the system may be able to assume that person will have more patience and be motivated to engage. They may be anxious to dive into the details more quickly and thus there may be less need to deliver motivation-inducing content. These are hypotheses that would need to be investigated, of course, and affect detection technologies could play a key role in conducting those studies to see if adaptive changes do increase the number of visitors who choose to engage, for how long, and to what end.
5.3 Application area 3: Sustaining engagement

As discussed earlier, engagement is a rich concept that involves behavior, emotions, and cognition. Attempts to strengthen engagement benefit by addressing all three categories as well as the interactions between them. Although the application of good design principles can promote engagement (Humphrey, et al., 2005; Perry, 2012), it is not at all clear that a ceiling has been reached in terms of the depth and quality of engagement possible in informal learning environments. In fact, sustained engagement is often associated with highly pleasurable and engulfing experiences sometimes referred to as flow states that carefully balance challenge with skill level (Csikszentmihályi, 1991). A variety of measures have been proposed and validated for assessing and tracking flow, including some that distinguish between different flavors and properties of flow experiences (Martin & Jackson, 2008). Despite the controversy surrounding formal definitions of flow, notions of task absorption and engagement share important similarities that may provide theoretical guidance on how to leverage user sensing technologies for adaptive informal learning experiences.

Unfortunately, it is unclear whether flow is always desirable in learning contexts. For example, several studies have demonstrated the value of confusion during learning (D’Mello et al., 2010), which is not normally considered a pleasurable state. Reaching a confused state implies that some learning has occurred – it is a normal developmental stage on the way to deep understanding. The risk for confusion, of course, is that it may persist for too long and devolve into frustration, a key trigger for disengagement. James Gee, using a different sense of the word, has described good games as being “pleasantly frustrating” because they can motivate players to seek to learn more than the bare minimum needed for success (Gee, 2003). As a final example of why flow may not always be the ideal construct for learning, when experts are engaged in deliberate practice, they have been found to purposely avoid flow states in order to perfect their skills and maintain growth (Ericsson & Ward, 2007). In this case, it is a matter of experts not wanting to “get too comfortable” and desiring to understand and correct their weaknesses.

In terms of adapting an exhibit to promote sustained engagement, the availability of a monitor or speakers would make it possible to deliver appropriate help messages to a visitor or group of visitors with the goal of promoting their involvement. If feasible, an exhibit could also be equipped with an intelligent tutoring system to monitor user actions and provide guidance at appropriate times via a pedagogical agent (Lane, Noren, Auerbach, Birch, & Swartout, 2011). In the case of confusion, there may be a limited window of time in which to support resolution of the confusion and prevent disengagement, so it is critical to ensure that issued challenges are at the right level of difficulty. This could even be influenced by estimated ages of visitors based on height, or other detectable physical traits. If the experiences are virtual, it may even be possible to adjust the corresponding simulations on the fly to further increase or decrease difficulty as needed (Lane & Johnson, 2009).

Returning again to museum fatigue, although generally believed to have a detrimental impact on visitors’ choices, learning, and experience (Davey, 2005), significant open questions remain regarding its causes, effects, and best strategies for amelioration (Bitgood, 2009).
detected, it may be beneficial to proactively adjust the level of challenge and depth of content to increase the chances of at least limited forms of engagement. In other words, assuming that cognitive processing is a contributor to museum fatigue, it would suggest that a fatigued visitor approaching a new exhibit may be less willing or even unable to accept complex content.

5.4 Application area 4: Promoting productive conversations
Conversations between museum visitors and with staff play a critical role during visits to museums (Leinhardt & Knutson, 2004). As mentioned, the quality of these conversations often predict how much learning occurs and whether affective outcomes are achieved (see Perry (2012) for an extended discussion of the social nature of learning in designed spaces). How might an adaptive exhibit adjust its presentation to promote such conversations?

Conversational behaviors of groups can vary dramatically based on the makeup of the group, such as age and relationships. Extensive studies of group behaviors at exhibits uncovered some expected and unexpected results (McManus, 1987, 1988). For example, singletons tend to read signage to a high degree, whereas groups with children spent most of their time in conversations and not reading, except for occasional glances to support conversational goals. Groups of adults, interestingly, tended to not engage in exhibits as deeply, whereas couples have lower levels of conversation and read more extensively. What is interesting about McManus’ findings is that it suggests the makeup of the group is a reliable predictor of the way they will use an exhibit. So, if a vision system could classify a group as they approached, and used monitors to present information accordingly, the system could adaptively present the same information in different ways. For example, a group with children could provide with shorter nuggets of information that might be useful to the adults as the interacted with the children. If the exhibit was able to also track actions being taken, this information could easily be aligned with their activities (e.g., providing explanatory knowledge after an experiment is run).

Moving beyond these basic categories, current technologies also are able to recognize nonverbal cues for understanding, such as head nodding behaviors (Morency, et al., 2005). Combining these inputs with detected speech (regardless of understanding) could enable even richer models of conversations occurring at exhibits. In essence, exhibits could be aware of (1) if visitors are talking about the desired content and (2) the general tone and attitude of the conversational participants. An exhibit that could classify the conversations taking place along these lines could adjust its operation, such as providing information on lower screens for younger visitors providing them with information specifically for them to increase participation or think of good questions. If completely off-topic conversations were detected (which could likely be inferred by combinations of gaze and speech patterns), the exhibit could seek to gain the attention of the visitors by presenting a surprise, adjusting lighting, or making attention-grabbing sounds. Of course, if the exhibit was inhabited by a pedagogical agent, this agent could attempt to draw the group in through humor or intrigue. The social affordances of an agent could also lead to interesting modes of reflection on the experience and, possibly, adjusting behavior based on conversations judged as negative or positive. A generally negative conversation might lead to
an interaction on how to improve the exhibit, or a positive one could focus on what was best and why. The idea of a “self-modifying” exhibit based on large data sets could quickly open up the techniques educational data mining to informal learning.

6 Challenges and future research
Although the last decade has seen tremendous progress in user-sensing technologies, there are still many fundamental problems that need to be addressed. Most importantly, many informal learning institutions are loud and busy environments that pose significant challenges for speech, vision, and affect detection in general. As the field progresses, these environments represent intriguing opportunities to test the robustness and fault tolerance of new algorithms. The primary goal of adaptive educational systems is to be responsive to individual differences between learners, and so improvements in affect detection technologies will lead to an improved ability to adapt. The vision to build “adaptive museums” represents a new set of challenges for user modeling, intelligent learning environments, and informal education research.

The key to adaptive systems lies in their ability to model learners as accurately and appropriately as possible. This is extraordinarily difficult in a museum setting: visitors come with different agendas, with widely different backgrounds, often are part of groups, and have very brief learning experiences. Physically tracking an individual learner around a museum is possible with RFID or GPS technologies, but it is not easy to make accurate inferences about their learning, interests, or emotions from this data alone. Thus a key challenge lies in interpreting multiple, heterogeneous sources of inputs into a reasonable model that can feed an adaptive system. The task of mapping these often very different clues into estimates of visitors’ emotions, thinking, and goals presents brand new directions for informal learning research.

Of course, visitors do not enter museums as blank slates. Having some understanding of background or incoming knowledge of visitors points to the need for lifelong and sharable learner models (Kay, 2008). Thus, a visitor attending a museum would need to proactively share his or her learner model (only the relevant parts), so that personalized information could be provided, either via a mobile device or actually at the exhibits themselves. Of course, privacy must be respected and so museums would need to provide visitors who are neither willing to be identified nor share their information with the traditional “one-size-fits-all” approach historically used. On the other hand, museums very often have membership arrangements with local visitors and such existing relationships may engender higher levels of trust. Exhibits could recognize return visits and provide them with adapted experiences that reflect prior exposure to the topics.

Ultimately, the success of a designed informal learning space depends on the quality of the experiences visitors have. In this chapter we have argued that emotions play a big role in the decisions visitors make and that affect-aware technologies can be used to enhance these experiences. Although we have focused on the very specific challenge of designing interactive exhibits – and promoted the use of digital technologies to increase the level of possible adaptivity – there is a much larger view of informal learning to address. “Free-choice” learning involves choices made throughout life. A visit to a museum, science center, or zoo is an
educators opportunity to highlight the joys of learning and the value of self-improvement. We want visitors to not only gain a little knowledge and maybe, change their behaviors, but also to leave as better decision-makers. In the pursuit of more deeply engaging experiences, sometimes the goal to “entertain” visitors, rather than educate, can threaten learning goals (Shortland, 1987). But in the end, learning, changing, and feeling go hand-in-hand, and so it makes sense to always design with these in mind and leverage the full capabilities of modern technology to achieve society’s educational goals.

References


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