An evaluation of multimodal interactions with technology while learning science concepts

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RESEARCH ARTICLE

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A Human Factors Study of Technology Acceptance of a Prototype Mobile Augmented Reality System for Science Education

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This paper presents a novel implementation of an extended technology acceptance model to gain insight into user perceptions, attitudes and beliefs toward a mobile augmented reality system for science education. Results were collected during the initial testing of a prototype system, with the specific intent to diagnose misspecifications of user requirements, receive appropriate feedback and integrate it within the design lifecycle of the product. The research model used in this study monitored several affective, motivational and cognitive factors of user acceptance. Findings from the study show that the augmented technology acceptance model accurately represents student evaluation and reactions, even after a short initial experience of hands-on usage of the system. Empirical evidence supports moderating effects upon the core perceptual constructs by taking into account wearability aspects across dimensions of user comfort and exertion, and gender differences as well.

Keywords: Technology Acceptance, Usability Evaluation, Wearability, User Requirements, E-Learning, Augmented Reality.

1. INTRODUCTION

The design and implementation of novel interactive systems presents a significant challenge to human factors' considerations. Traditional methods of task analysis fail to capture key user needs and prove to be ineffective in accounting for salient factors within the intended context of use.[1] The alternative approach of eliciting requirements directly from users can be equally problematic, as participants do not necessarily base their considerations upon future tasks and technologies, but prefer to focus on those with which they are most familiar. It is often useful to differentiate between two broad categories of problems concerning the development of novel interactive systems: (1) problems in realizing *specified* user requirements due to design or implementation error, and (2) problems in the accuracy of requirements due to discrepancies between the *specified* user requirements and *true* user requirements.[2] The latter may be of particular importance, especially when multidisciplinary teams are working on a common task. Gaining insights into the origin and misspecification of user needs, and elaborating upon the key perceptions upon which users base their evaluations, during the early stages of the development lifecycle, can provide substantial benefits to system designers in minimising the risk of technology rejection by the intended users. This study investigated major users' acceptance characteristics during the implementation of a mobile Augmented Reality (AR) system that was designed for science education, by applying an empirically verified model of technology acceptance. In identifying key factors of user adoption and making informed design decisions based upon them, designers can assess the appropriateness of the technological solution for the specific needs of the users. This in turn maximises the potential for return on investment through the selection and implementation of appropriate technologies and learning content. In applying the Technology Acceptance Model (TAM) to the domain of educational technology, it is anticipated that a greater understanding is gained on what kind of affective, motivational and cognitive variables contribute to the acceptance of technology. Additionally, a usability measure, as specified by ISO 9241-11,[3] is integrated within TAM, namely the affective component of user satisfaction. This model is then utilised in testing hypothesised gender effects, and in validating ergonomic requirements for wearable technologies,

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mainly dimensions of user comfort and exertion.[4,5] This testing can support the argument that ergonomic standards and other data sources, concerning human characteristics, are often misinterpreted or misused, even when such data are taken into consideration in the first place. When such methods are misapplied, the investigation is prone to a wide range of problems, particularly with respect to content presentation, issues of usability, lack of focus and relevance on the target audience, poor refresh schedules and obsolescence.

Current conceptions of usability typically investigate whether technology is, or will be, used, and examine the extent to which technology is 'fit for purpose'. This approach usually overlooks that the use of technology can often be optional. For example, in environments where people can choose to use technology or not, the first challenge should be to get people using the technology in the first place. The domain of application for the present work is problematic from two points of view: firstly, the target audience, i.e., adolescents, might not be able to provide clear and complete sets of user requirements, while this may be further compounded by the intended domain of education, i.e., what are the specific requirements that are important for the development of educational technology? Secondly, the target technology is novel and for the most part unfamiliar to end-users. Human factors processes based upon guidelines, heuristics and checklists are often considered to be somewhat arbitrary, which raises questions as to the suitability and ability to be generalised across different technology domains and applications.[6] While it may be possible to adapt traditional methods of human factors research, it is felt that an alternative approach may prove more valuable, particularly when early technology development results in functional prototypes for specific domain applications. It is therefore proposed that TAM can compliment more detailed usability evaluations conducted at a more granular level, in offering a formalised methodology of data analysis, as well as validated instrumentation for obtaining user perceptions, beliefs and intentions in using the technology within the intended context of use, based upon the *overall user experience*. This premise is supported by Baber,[7] in asserting that usability should be considered as a shorthand description of the complex inter-relationship between people and technology, and most definitely not as an attribute of a product. Such an attribution fallacy stipulates usability as an interface quality that can be governed by the presence or absence of specific interface features, leading to an over dependence on guidelines, heuristics and prescriptive checklists for the design, as opposed to targeting the overall experience between people and technologies.

This paper presents a brief overview of the application domain and the underpinning theory of TAM. An extended model of acceptance is consequently presented, incorporating human factors as moderators and aspects of affective satisfaction. The model is then rigorously tested for validity, so that empirical conclusions can be drawn. The paper ends with a discussion of concerns highlighted by TAM within the educational domain and implications of human factors for the design of future interactive systems.

2. APPLICATION

The concept of AR incorporates the use of technology applications that allow the use of 2D or 3D scenes of synthetic objects to enhance and augment the users' visual perception of the real environment.[8,9] The co-existence of computer-generated virtual objects and the real environment constitute a "mixed-reality," where users can interact with the environment through appropriate input devices in real-time. Azuma[10] proposed three identifiers that define the field of AR:

(a) "AR combines real and virtual objects in a *real* environment;
(b) runs interactively, and in real time; and
(c) registers (aligns) real and virtual objects with each other."

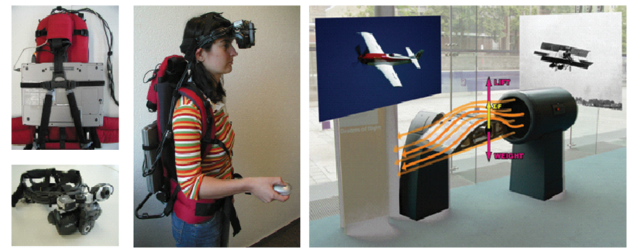

Fig. 1. A Student user of the CONNECT AR system (Left), Mock up of the Augmented User View of an Aerofoil Exhibit, Located at the @Explore, Bristol Science Museum, UK (Right).

The technological application used for this study is a mobile AR system for science education, developed as part of the CONNECT project (IST-507844). This approach used a technology-enhanced learning environment whereby users wear a Head Mounted Display (HMD) to augment their field of view, by way of virtual extensions to the real world.[11] This can aid the user in visualising typically non-tangible phenomena that are difficult to conceptualise via traditional methods, such as textbooks or different forms of multimedia. Multimedia tools capitalize on the students need for more interactivity that has shown to enhance students' beliefs in enhanced learning.[12] In adding virtual content, such as airflow, magnetic fields or force variables to the users real world view, it AR provides a mixed reality solution to science teaching. AR and truly wearable technologies are viewed as an emerging technology that is not yet commonplace within the public domain. The potential for useful and productive applications within all encompassing domains, such as education, manufacturing and maintenance,[13] defence,[14] surgery[15] and emergency services[16] are widely documented. Although users of the system may be accustomed to using interactive systems, such as, personal computers and mobile technologies, mobile phones and MP3 players, the AR system that comprises of a HMD and backpack (containing the CPU), as identified in Figure 1, represents a completely new experience, whereby existing factors of acceptance may be challenged and a totally new set of factors may be manifested.

3. THEORETICAL FOUNDATIONS

User acceptance has been widely investigated within the management and information systems literature. Several models have been proposed to explain and predict prospective technology usage including task-technology fit, the theory of planned behaviour and the theory of reasoned action (TRA). TRA proposes that beliefs and implicit evaluative responses formulated by the user during hands-on interaction directly affect attitudes and future behavioural intentions.[17] Behavioural intentions are strongly argued as being the most accurate criterion obtainable

Fig. 2. A Simplified Acceptance Model, based on the Theory of Reasoned Action (TRA).

in predicting future actions of users.[18] Within this model, beliefs and evaluations are direct responses to external stimuli, typically perceptions of the technology and other contextual factors. Behavioural attitudes are defined by the values held by the user with regard to the consequence of the specific future intended behaviour. Figure 2 shows a simplified causal chain of acceptance, adapted from TRA, identifying the key issues that have been already discussed by Shepherd[18] and others.

For any prediction to be easily deduced and be reliable, models must adhere to the correspondence principle, stipulating that user beliefs and attitudes must be specified in a manner that is consistent across time, target and context with the behaviour of interest.[17] TRA relies on this theory to predict intention and adoption, by identifying beliefs and attitudes about a specific behaviour (e.g., the use of an AR system), in a particular context (e.g., science education), at a particular point in time (e.g., this week). Attitudes toward the desired *behaviour* are fundamental to this premise, as opposed to attitudes toward an outcome or condition. For example, focusing on attitudes towards *learning science* is more insightful than focusing on attitudes toward becoming a scientist. TRA provides the influential theory underpinning the development of TAM, which was first developed by Davis (1989) to explicitly explain and predict computer usage behaviour. TAM denotes two key perceptions as predictors of a user's intended future behaviour, namely, usefulness and ease of use. Perceived usefulness is defined as the users' "subjective probability that using a specific application system will increase his or her performance within an organizational context."[19] Perceived ease of use refers to "the degree to which the user expects the target system to be free of effort."[19] Consistent with TRA, the users' attitude toward use mediates the relationship between these two cognitive measures and intention, and is defined as being the users' desirability toward using the system. The core TAM model is presented in Figure 3.

Since its introduction, TAM has been widely investigated and empirically validated in the Management Information Systems (MIS) literature, accounting for up to 10% of yearly publications in credible MIS journals[20] indicating that TAM became a major stream of research effort. The target applications of the model have been anchored to common desktop-based information systems, such as, email, general internet usage, word processing and spreadsheets,[21] while the more outreaching have investigated groupware,[22] expert support systems[23] and telemedicine technology.[24] Undoubtedly, TAM is mainly used in a traditional sense for predictive purposes at, or shortly prior to, the point of considering implementation, which implicitly infers that a technology has reached a level of maturity acceptable for commercialisation. There have been minimal investigations into how users experience changes with technology over the course of a technologies maturity, or the observed effects when innovative technologies break away from the grey box paradigm of desktop personal computers and challenge users to adapt to new interaction and presentation mechanisms.

Future research may profitably seek to establish how early in the development process of a system, for example, even before a working prototype is built, we can measure key user reactions, such as perceived usefulness and intention, and still rely on them as indicators of post implementation success of the system.[25] Initial research into this area, by Davis and Venkatesh,[2] has established that robust perceptions of usefulness can be gained using low fidelity system prototypes, but hands-on usage is required before perceptions of ease of use can be reliably made. This study adds to this current research theme by investigating user evaluations of a prototype system after an initial hands-on experience. Furthermore, this investigation posits further usability factors to the core TAM model within the domain of education and future innovative technologies.

4. RESEARCH MODEL AND HYPOTHESIS

4.1. Model Specification

Figure 4 details the research model that will be tested in this study. Recent TAM studies have sought a more parsimonious model and consequently omitted the attitude construct. However, attitudes are central to the framework of TRA and considered particularly important within an educational setting.[26] Within this context, students may not believe that using the system or any other form of interactive multimedia is the most effective way to learn. Consequently, students may not even use the tool at all within a discretionary context, such as a science centre. This opposes the traditional TAM research, which is focussed on intention to use within a work environment, whereby use is typically non-voluntary. Students have the option to choose which educational tools to use and the extent to which these tools will be utilised.

This study posits that attitudes related to affect and cognition are considered as two distinct mental faculties. This is supported by substantial theory suggesting that affect operates as an independent process and serves as input to both cognitive and behavioural operations.[27] Research in this area, by Blascovich and Tomaka[28] and Forgas,[29] suggests that affective states arise

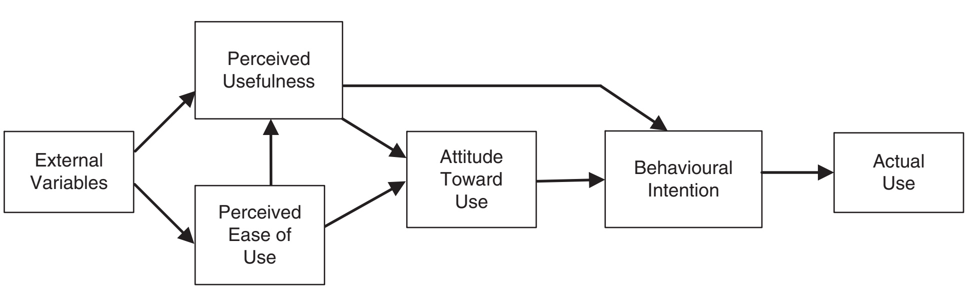

Fig. 3. The TAM model based on Davis.[19]

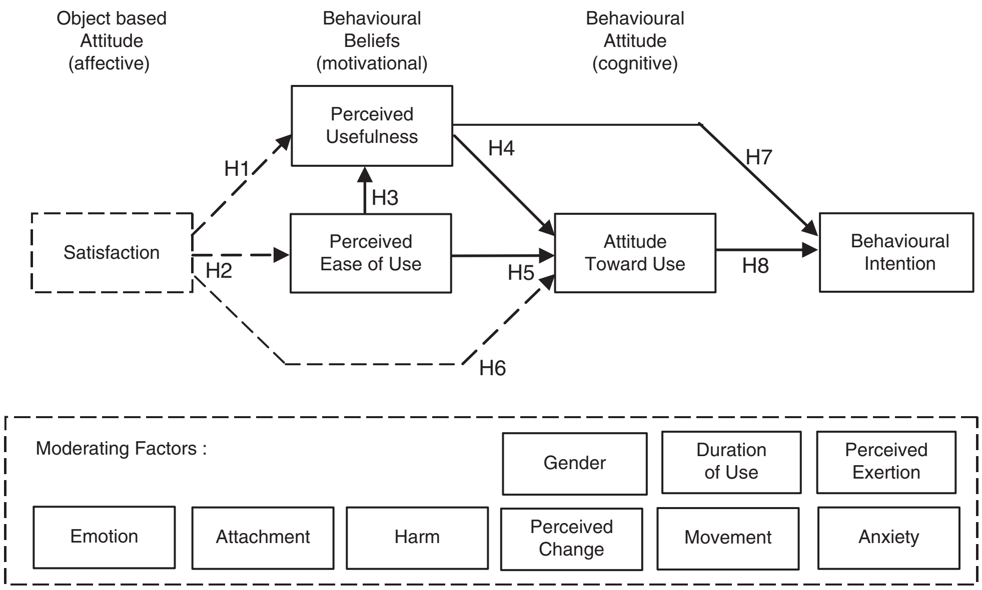

Fig. 4. Hypothesized relationships between TAM constructs (solid lines represent constructs and relationships based on original TAM model and dashed lines represent added factors).

prior to highly structured cognitive processes and that such 'pre-cognitive' affective reactions function as a predictive entity to motivated behaviour. Affect incorporates various aspects of users' moods, emotions and feelings and is considered a fundamental aspect of human nature.[1,30] Furthermore, it has been recognized that emotively pleasing technologies work better, are used more regular, are easier to learn, and produce a more harmonious user experience. Thus affect and emotion should have an important role in the design and evaluation of interactive technologies.[1] In this respect, affective reactions as evaluative responses are hypothesised to influence users' motivational beliefs toward ease of use and usefulness, while these can in turn influence subsequent behaviours. With respect to technology acceptance, Yang and Yoo[31] differentiated between affective and cognitive attitudes, as how much the user likes the object of thought[32] and an individual's specific beliefs related to the object,[33] respectively. Yang and Yoo[31] concluded that cognitive attitudes are good predictors of use in mediating the relationship between user perceptions of usefulness and ease of use with actual usage of the system, but they established no predictive power with the affective dimension. The present study specifies affect as a core component of user satisfaction, which is a central theme within the usability literature, and is incorporated in satisfaction ratings, such as SUMI,[34] and legislated for by ISO 9241-11. Thus, satisfaction is conceptualised as the affective response to the extent with which users like the target system, and is therefore viewed as an object-based belief.[35] Whereas object-based attitudes and beliefs have previously been found to be poor predictors of technology acceptance[36] and user satisfaction in particular, while also identified as a weak predictor of system usage,[19,37,38] there has been sparse distinction between the cognitive and affective factors of such investigations. Conversely, research into Perceived Affective Quality (PAQ) has consistently found core affects to be significant antecedents of ease of use and usefulness perceptions.[30] However, these studies have not provided a clear distinction between cognitive and affective processing systems in studying attitudes per se. Consistent with PAQ studies, it is hypothesised that a person perceiving IT to be positive and stimulating, and thus indicating a high level of affective satisfaction, will be more likely to perceive IT as more easy to use (H1). Similarly it is also hypothesised to be more useful in performing a specific task (H2).

4.2. Moderating Factors

As shown in Figure 4, a variety of moderating factors will be investigated within this study. It is hypothesised that these factors will have a significant effect upon the core constructs of TAM. Differences between gender will be also studied to investigate whether females indicate equivocal levels of acceptance as male users of the system. The duration of use will be also investigated to examine whether users who interact with the system for shorter time exhibit comparable perceptions as users who interact with the system for longer time. Due to the wearing the AR system, exertion will be measured using the Borg Relative Perceived Exertion (RPE) scale[39] as an approximation measure of overall physiological effort (Fig. 5). A general rule of thumb, when using the scale, is that multiplying the rating value by 10 gives an approximation to heart rate. A value of 13 (somewhat hard) should relate to a heart rate value of around 130 bpm. For the purposes of this study, a pre- and a post-test measurement were obtained, and the difference between these two values was used as an indicator of exertion, whilst interacting with the system.

In addition to exertion, the overall sense of users' well-being will be determined with an assessment of comfort. Measuring comfort across six dimensions, the comfort rating scales (CRS) were developed specifically for the assessment of wearable computers.[7] The six dimensions are Emotion (concerns about appearance and relaxation), Attachment (comfort related to non-harmful sensation of the device on the body), Harm (physical sensation conveying pain), Perceived change (non-harmful indirect physical sensation making the wearer feel different overall with perceptions such as being awkward or uncoordinated, may result in making conscious compensations to movement or

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Fig. 5. The Borg Relative Perceived Exertion (RPE) scale.

actions), Movement (conscious awareness of modification to posture or movement, due to direct impedance or inhibition by the device), and Anxiety (worries as to the safety of wearing the device and concerns as to whether the wearer is using it correctly or it is working appropriately). By measuring across these six dimensions, the CRS attempts to develop a comprehensive assessment of the comfort status of the wearer. It is hypothesised that comfort will have confounding effects upon the core constructs of technology acceptance.

5. METHOD

A cross validation technique was implemented, whereby the model was developed using a calibration sample and then confirmed using an independent validation sample. The calibration sample utilised results gained from the first phase of testing ($n = 80$), while the confirmation sample used results from the second testing phase, after minor improvements had been made to the system ($n = 90$). Different participants were used in each sample and, therefore, a longitudal analysis was not considered as appropriate in the context of this study. For the sake of brevity, only the pooled results are presented here. The models were tested using a nested approach in Amos 6.0 to attain appropriateness of pooling through the progressive constraints of the measurement approach. Pooling was appropriate based upon these results and was considered necessary to gain adequate sample sizes for reliable estimates of the hypothesis testing and for investigating the effects of the moderating factors.

5.1. Participants

The sample group was composed of users from four European Union countries, who were visiting respective science and technology centres, as part of planned school visits. This group of users was deemed representative of the potential group of users of the CONNECT mobile AR system. In total 91 males and 79 females participated in the study. Further details concerning the sample can be found in Table I.

5.2. Scale Development

The TAM items were adapted from previous studies to preserve validity and reliability of the core constructs; Perceived Ease of Use (PEO); Perceived Usefulness (PU); and Behavioural Intention (BI) and facilitate the comparability of findings.[2, 22, 25] The satisfaction construct was added after selecting appropriate affective semantic differential items from the Questionnaire for User Interface Satisfaction (QUIS)[40] usability satisfaction questionnaire, based upon the recommendations from Crites et al.[41] Crites and colleagues defined affective scales as the position that best describes respondents' feelings toward the object, whereas the cognitive scales (ATU) indicate the position that best describes the traits or characteristics of the object, which are conceptualised in this study as attitudes toward the desired behaviour. Participants indicated their level of agreement based on a seven point Likert scale, whereby 7 indicated strong agreement and 1 indicated strong disagreement, except for ATU that used a 7 point semantic differential and satisfaction (SAT) that implemented a 9 point semantic differential. A pre-test was conducted on the scale items, using 30 participants to assess the face validity of each scale that was used within the final study. The pre-test was adapted according to the feedback obtained, but these results are not used in the work reported in this study. The questionnaires were translated into the native languages of the users prior to the study, following a rigid translation procedure.[42]

Table I. Descriptive statistics for study participants.

Demographics	No. of users	Age range	Mean age	SD
Sweden	33	15–16	15.30	047
UK	48	13–14	13.83	0.38
Greece	63	15–17	15.37	0.52
Finland	26	12–13	12.07	0.27
Total	170	12–16	14.42	1.27

5.3. Tasks

All users were given an initial introduction to the AR experience via a short group demonstration, and interacted with the AR system for an average duration of 8.25 minutes (SD 3.18). Questionnaires were administered immediately after their interaction. This means that the analysis is based on users moving from completely naive, with respect to the use of the technology, to having an initial experience. While this does not address issues associated with long-term use, it does provide a very good reflection of the type of environment in which the technology is proposed to be used. For example, visitors to a museum may be provided with the technology and if, after a few minutes experience, it performs satisfactorily and they can see its potential benefit, they will continue to use it. On the other hand, if this initial experience is unsatisfactory, then intention to continue using the system will be very low. The specific tasks users were required to perform varied between each science centre, due to the different exhibits that were augmented. The nature of tasks involved hands-on interaction with the physical exhibit, manipulation of variables viewed via the HMD and observation of the virtual extensions, thus implementing generic selection and observation tasks.

6. RESULTS

6.1. Scale Assessment

The scales were tested for construct validity using common factor analysis (principle axis factoring) with promax rotation. An oblique rotation was used, so that factors are free to correlate, and is a preferred method when using Structural Equation Modelling (SEM). The number of factors was specified by examining the scree plot recommending units. To assess discriminant validity, all variables should load significantly upon its intended construct, but always less to the other constructs. As can be seen in Table II, all items loaded on their intended construct by at least the 7 level suggested by Nunnally and Bernstein[43] and no cross loadings were within the alternate constructs.

Since the data was collected from a single source (e.g., self-report questionnaire), there exists a possibility for the occurrence of common method variance.[44] A Harman single factor test was conducted, using exploratory factor analysis on all 18 items, to determine the extent of common method variance in the collected data. For unique variance to be obtained, the factors are forced to be uncorrelated, and therefore an orthogonal analysis with varimax rotation was used. The total variance explained by the five factors was 76.2%, with explained variance ranging from 12.87% to 18.45% for each factor. These results suggest that no single factor could explain most of the variance, indicating that the common method bias is not suspected as a likely contaminant of the results observed in this study. Cronbach's alpha was further used to assess scale reliability and, as it is shown in Table III, all factors are above the suggested .7 threshold, indicating good construct reliability.[43]

Fornell and Larcker[45] further suggested that average variance extracted (AVE) can be used to evaluate discriminant validity. The method to assess the discriminant validity of the constructs in this study requires that the square root of AVE for each construct should be greater than the correlations between that construct and all other constructs. Table IV shows the correlation matrix of the constructs with the AVE on the diagonal. This value should be higher than any correlation within either the horizontal or vertical correlation matrix. In this study, the assessment of discriminant validity did not reveal any problem.

6.2. Measurement Model

The hypothesised model, shown in Figure 6, was then subjected to rigorous testing using the Structural Equation Modelling (SEM) package; Amos 6.0 to test the measurement model for adequacy. The results of the full SEM analysis as well as the confirmatory factor analysis can be seen in Figure 6.

Assessment with respect to exact model fit is principally assessed by the *p* value of the chi squared test statistic. Ultimately, this should be non-significant as this test is in effect a *badness of fit* test. The value of 13 signifies that the model is an excellent fit for the data collected. Further fit statistics, which address parsimony, complexity and sample size have been suggested by various sources including Hu and Bentler[46] and are shown in Table V.

Although the model provides a good fit to the data, but there are several points that deserve further exploration. The relationship between PEO and ATU was found to be insignificant, while previous research has questioned the stability of the PEO construct as results have been mixed. Sun and Zang[21] discussed that 6 linkages, out of 19 models that were studied, reported insignificant relationships between PEO and ATU. The results of the study further support the argument that perceived ease of use is not a stable measure of acceptance across different technologies, applications and levels of user experience.[19,46,47] This indicates that unless the user perceives the system as being useful first, then the ease of use of the technology has no influence on user attitudes and intentions to use. However, given a situation whereby users perceive two technological systems to have equivalent usefulness, the system that is perceived to have higher ease of use will be used.[19] Satisfaction had a significant effect upon all hypothesised TAM constructs, in particular those related to perceived usefulness. Overall 64% of the variance in intention was explained by the model, whereas typical TAM studies often mediate at 40%. This result signifies that ease of use, usefulness, user satisfaction, and attitudes toward use are highly significant

Table II. Factor analysis of TAM items principle axis factoring with promax rotation. Rotation converged in 5 iterations.

	Factor				
	1	2	3	4	5
PEO1	**.824**	.237	.469	.230	.353
PEO4	**.935**	.229	.476	.188	.378
PEO5	**.827**	.253	.456	.236	.363
PEO6	**.824**	.233	.453	.214	.320
SAT3	.204	**.760**	.387	.342	.423
SAT4	.249	**.719**	.330	.247	.319
SAT5	.227	**.841**	.351	.381	.478
SAT6	.163	**.767**	.323	.348	.419
PU1	.441	.287	**.768**	.312	.425
PU4	.484	.357	**.762**	.415	.528
PU5	.481	.453	**.898**	.515	.640
PU6	.380	.421	**.826**	.534	.645
ATU2	.207	.347	.344	**.788**	.499
ATU3	.180	.332	.426	**.733**	.503
ATU4	.166	.278	.434	**.749**	.483
BI1	.341	.421	.647	.602	**.911**
BI2	.330	.487	.521	.521	**.827**
BI4	.410	.475	.585	.600	**.860**

Table III. Descriptive statistics of the items used within the study.

Latent variable	Item	Scale	Mean	SD	Cronbach's alpha
Satisfaction	Sat1	9	6.03	2.02	.85
	Sat2	9	6.35	2.15	
	Sat3	9	6.19	2.14	
	Sat4	9	6.34	1.87	
Perceived ease of use	Peo1	7	5.61	1.32	.91
	Peo2	7	5.38	1.34	
	Peo3	7	5.45	1.35	
	Peo4	7	5.42	1.25	
Perceived usefulness	Pu1	7	5.04	1.29	.88
	Pu2	7	4.86	1.51	
	Pu3	7	5.01	1.42	
	Pu4	7	5.07	1.26	
Attitude towards use	Atu1	7	5.61	1.06	.80
	Atu2	7	5.58	1.08	
	Atu3	7	5.68	1.08	
Behavioural intention	Bi1	7	5.35	1.51	.90
	Bi2	7	5.00	1.68	
	Bi3	7	5.44	1.49	

Table IV. Correlations between constructs shown off-diagonal. AVE shown in bold on the diagonal.

	Sat	Peo	Pu	Atu	Bi
Sat	**.769**				
Peo	.264	**.854**			
Pu	.499	.546	**.813**		
Atu	.457	.304	.561	**.753**	
Bi	.435	.400	.734	.677	**.861**

Table V. Summary of fit statistics from the SEM analysis.

Fit statistic	Obtained	Recommended value
Chi-square	146.10 ($p = .13$)	($p > 0.05$)
Goodness of fit (GFI)	.92	>0.9
Adjusted goodness of fit (AGFI)	.89	>0.8
Parsimony Adjusted GFI	.69	>0.5
Normed Fit Index (NFI)	.93	>0.9
Comparative Fit Index (CFI)	.99	>0.95
SRMR	.045	<0.05
RMSEA	.03	<0.05
RMSEA—Lower confidence limit	.00	
RMSEA—Upper confidence limit	.05	

factors, when users are introduced to a completely new technological paradigm.

6.3. Moderating Factors

6.3.1. Gender

The next step was to include the suggested moderator variables into the model in order to gain further insights. Multiple group analyses were performed using a nested approach in comparing two sub-samples, which were selected according to gender or based on a median split of the respective moderating variables of comfort and exertion. Arbuckle[48] specifies that a model with equality constraints (e.g., Males) is compared to a model that allows the parameters to vary (e.g., Females). The purpose of testing latent mean structures is to test the equivalence of means related to each underlying factor. Because these factors cannot be observed directly, latent means can be calculated for one group only. The complete results of the gender analysis are shown in Table VI.

Table VI shows that there were two highly ($p < 0.01$) significant results from the analysis concerning gender. Females reported lower levels of satisfaction and usefulness. Furthermore, there was one significant ($p < 0.05$) reported measure of lower attitude toward use and one approaching significance ($p < 0.08$) result, indicating lower behavioural intention for females. Previous studies in educational research have examined the gender differences in perceived usefulness of computer technologies and found that male students consistently evaluated computer technologies as more useful than female students.[49, 50] Furthermore, there is a growing amount of evidence indicating that males are generally more experienced with, and hold more positive attitudes about, computer technology than females.[51] These differences should be taken into account for explaining the observed differences in satisfaction, attitude towards use and behavioural intentions. A more complete analysis of gender differences in e-learning acceptance is presented by Ong.[49] These results provide further evidence supporting the conclusion that males are more willing to use technologies within an educational setting.

Table VI. Results of latent mean analysis between male and female users. Males were used as the reference group. The significance values are as follows: ***$p<0.01$, **$p<0.05$, and *$p<0.08$.

	Estimate	Standard error	Critical error	p
SAT	−.747	.253	−2.963	.003***
PEO	−.022	.177	−0.126	.900
PU	−.469	.156	−3.008	.003***
ATU	−.306	.140	−2.192	.028**
BI	−.395	.222	−0.1778	.075*

Table VII. Gender differences between the direct and indirect effects of SAT, PU, PEOU and ATU on BI.

		Entire sample				Female (N) = 79				Male ($N = 91$)			
		PU	PEO	ATU	BI	PU	PEO	ATU	BI	PU	PEO	ATU	BI
Direct effects	SAT	.38	.26	.24		.44	.18	.25		.22	.37	.23	
	PU			.44	.52			.46	.52			.39	.51
	PEO	.45				.46				.52			
	ATU				.39				.42				.36
Indirect effects	SAT	.12		.22	.44	.08		.24	.48	.19		.16	.35
	PU				.17				.19				.14
	PEO			.20	.31			.21	.33			.20	.34
	ATU												
Total effects	SAT	.50	.26	.46	.44	.52	.18	.49	.48	.41	.37	.39	.35
	PU			.44	.69			.46	.72			.39	.65
	PEO	.45		.20	.31	.46		.21	.33	.52		.20	.34
	ATU				.39				.42				.36

To evaluate the relationships between constructs regarding issues of gender, the unconstrained models (whereby all parameters are free to vary) for males and females were calculated. The results of this analysis can be seen in Table VII.

The most compelling differences observed on the moderating effects of gender can be seen in the role of affective satisfaction. The total effects of satisfaction on attitudes towards use and behavioural intention for females is statistically significant ($p < 0.01$). There is evidence to support the premise that female's show a relatively high tendency toward emotion, of which affect is closely related to Ref. [52]. A more detailed analysis of the data in Table VII reveals that this discrepancy can be principally attributed to the larger direct effect of satisfaction on usefulness for females ($p < 0.001$), while males satisfaction has a stronger direct effect on ease of use than females ($p < 0.001$).

6.3.2. Comfort

Further analyses were conducted for the measures of user comfort and perceived exertion. Table VIII presents descriptive statistics for the dimensions of the measure of user comfort.

In each case, the users who reported higher levels on each variable were used as the reference group. Based upon the results of the gender analysis, and to err on the side of caution, so that gender differences did not contaminate the results, a stratified median split was used, so that equal numbers of males and females were in each High/Low group. T-tests were calculated to examine whether the mediating variables related to comfort and exertion influenced the observed gender differences. There were not any statistically significant differences between gender differences of these variables. However the "emotion" dimension could be considered as approaching significance ($p < 0.08$) in that females (6.03 ± 5.40) scored higher than males (4.62 ± 4.51), suggesting that females were more embarrassed and self-conscious wearing the system. The results of the Latent Mean Analysis between

Table VIII. Descriptive statistics for dimensions of user comfort.

Latent variable	Item	Scale	Mean	SD	Cronbach's alpha
Comfort	Emotion	20	5.27	4.98	.75
	Attachment	20	7.69	5.76	
	Harm	20	4.25	4.76	
	Change	20	7.33	5.70	
	Movement	20	8.49	5.71	
	Anxiety	20	4.75	4.81	

Table IX. Summary of the Latent Mean Analysis between dimensions of comfort and perceived exertion. Key for significance levels: ***$p<0.01$, **$p<0.05$, *$p<0.08$.

	Emotion	Attachment	Harm	Perceived change	Movement	Anxiety	Perceived exertion
SAT	**				***		
PEO				*			**
PU	**				*		
ATU	**	*	***		*	*	**
BI	***		*				

the dimensions of comfort and perceived exertion are shown in Table IX (note that to save space only the significance levels of mean differences are indicated.).

Observations of the highly significant effects of user comfort on the TAM constructs indicate that users' perceptions of restricted movement, whilst wearing the system, had a major influence upon user satisfaction. There was also a highly significant effect of user perceptions of harm on the users' attitude towards use. Given that attitude denotes cognitive attitudes about a *specific behaviour*, this result implies that the health and safety of the user is paramount to technology acceptance, and this also has a direct bearing on user intentions. User emotion has a pervasive influence upon the majority of the TAM constructs, indicating that the way the system makes them feel, and self perception regarding how the users look to their peers is central within the context of this study. This may be due to the age of the user group used in this study, but the direct influence on behavioural intentions should be of major concern in system development and the user requirements' management processes. Ease of use was only marginally effected by comfort, in that perceptions of how "different" users felt when wearing the system had a moderate effect on how they were able to operate the system, perhaps due to adopting new interaction methods that were not as familiar or natural. It is clear from Table IX that the dimensions of user comfort have a profound influence upon the user attitude toward use, and that the multidimensional attributes of comfort should be considered mainly as cognitive processes of wearability.

The Borg Relative Perceived Exertion scales used to measure levels of energy expenditure, with no apparent change in work rate or level, can be used as an indication of physiological fatigue. A median split of the data was conducted based upon the observed difference between user ratings at rest (pre-test) and after interaction with the system (post-test). The results show that the users who indicated levels of physical fatigue had negative consequences on ease of use ($p < 0.05$), and also direct effects on user attitudes to use the system ($p < 0.05$). However, exertion was not perceived to significantly affect user satisfaction or usefulness, and ultimately had no direct effect on behavioural intentions. The duration of use that varied considerably among users was also tested. Interestingly, the duration of use had no significant effects, indicating that users who used the system for the shortest time period (2 minutes) were able to provide accurate measures of acceptance as users who used the system for 25 minutes. The average duration of use was 8.25 minutes with a standard deviation of 3.18. Future research would profitably seek to rigorously validate these findings by using a longitudal analysis comparing results from prototype testing studies with attitudes and beliefs held by users after the system has been implemented and prolonged use by users.

7. DISCUSSION

The TAM based approach to human factors evaluation is considered as 'sociological', in that the method seeks to develop an understanding of the responses that people have concerning their work and the technology.[7] Given this perspective, 'evaluation' becomes a matter of reflecting on such responses. This distinction on the definition of the term 'evaluation' is based upon the original classification of craft, engineering and applied science approaches to evaluation specified by Long and Dowell.[53] Whereas an applied science approach merely seeks to develop fundamental principles of human behaviour with technology, the sociological approach verifies theoretical understanding, by incorporating the context of use to reflect real life practices in real environments. An interesting observation of TAM is that ease of use is probably the closest concept to the notion of 'usability' found in the Human Computer Interaction domain. The implication is that while effort is put into usability during the design process, it might not have a direct bearing on the intention of end-users to actually make use of the system. ISO 9241-11 defines usability as "…the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." It has also been proposed that usefulness is theoretically indifferent to system effectiveness,[54] whilst the present study effectively modelled a core component of satisfaction as a determinant of user acceptance. This provides compelling evidence that TAM can be used effectively as a complementary evaluation tool, in particular when using a sociological approach for human factors evaluation. Adequate model fit and the indifferent results, found in investigating duration of use, suggest that user perceptions of a system are formed even after limited exposure to the system. Therefore, employing TAM is deemed theoretically appropriate for diagnostic purposes during early development stages of any new system.

A prominent finding of the study clearly indicates that perceived ease of use had no direct effect upon attitudes and intention to use. Although previous research established that this relationship was unstable across differing applications and contexts, this result was unexpected due to two distinct theoretical premises:

(1) Unfamiliarity of the users with the specific technology. Perceived ease of use has been reported to have a highly significant influence on attitudes and intentions, when users are first introduced to a system. This familiarity with the technology deteriorates over time.[25]

(2) In the domain of education, users direct their attention to the learning demands and the content, and the limited resources are taken up by learning and thus they do not operate and do not interact with the system. Davis[19] argued that the lower cognitive burden imposed by a technology, the more attention-based resources are made available for focusing on other matters, such as the learning content.

The insignificant effect of "ease of use" perceptions that was observed in this study could be attributed to the distinct nature of the technology and the task. AR systems are able to take advantage of natural gesture interaction; interaction using the CONNECT system allows users to freely move around the exhibit space and physically interact with tangible exhibit properties. The AR system tracks the position and orientation of the user and captures the variable states of the exhibit. Then the system updates the augmented view, within the HMD screen, according to these interactions. Therefore, the transparency or ambiance of the technology solution is suggested as being attributable to the low influential effects of ease of use. This limits the ability to generalise from this study that ease of use will have no significant effect on user attitudes for alternate AR tasks that employ different forms of interaction and manipulation. However, the results show that if users perceive the system to be useful, they are more likely to try a new technology if they perceive that little cognitive effort would be required for interacting with the system. This is important for technologies whereby usage is described as discretionary.

The affective component of user satisfaction was found to have significant effects upon user motivation and cognitive attitudes towards use. However, caution is always needed for [any] studies that report low standardised structural paths. Observations made by Meehl[55] support that the standardized paths should be at least 0.20 and ideally above 0.30, in order to be considered meaningful within a real world context. Anything lower may be due to what has been coined the *crud factor* whereby "everything correlates to some extent with everything else" due to "some complex unknown network of genetic and environmental factors."[55] Figure 6 shows that the relationships between satisfaction and perceived ease of use and between satisfaction and attitudes towards use were statistically significant, but should be interpreted with caution. However, given the strong relationship between satisfaction and perceived usefulness, the results could indicate that the evaluation or affective response focussed primarily on the content being provided to the users As the content was directed at the elucidation of specific museum exhibits, and as the content provided information that the users may not have previously had, such instruction could have been felt to the useful by individual users. Thus, the perceived usefulness could well have resulted from the contextualised presentation of content to the users, and how this new experience impacted users affective reaction. This would suggest that both the underlying concept of providing content in context, and the content itself, were perceived to be useful to the user group and contributed to their satisfaction. This premise was also supported by Wixom and Todd[56] who distinguished between system and information satisfaction, finding that *information* satisfaction had a significant influence on perceived usefulness, whilst system satisfaction significantly influenced ease of use.

Moderating effects regarding wearability provided insights into the effects of user acceptance, when systems go beyond the desktop. The results show that dimensions of comfort are principally cognitive evaluative responses with respect to future intended actions, with several comfort attributes serving ubiquitous effects among several indicators of acceptance. Most notably concerns towards harm, emotion and restricted movement of the user should be taken into account for the design of similar systems. Such results can be utilised in refining user requirements when considered within an iterative design lifecycle. Issues relating to gender can also reveal insights into individual differences, the differences in this study could be due to preferred learning styles, as well as generic attitudes towards technology.

8. LIMITATIONS OF THE STUDY

There are several concerns to be addressed when interpreting the results from this study. First, investigating the use of e-learning is a relatively new domain for acceptance research, and perhaps this is the first study to investigate wearable computers as a medium for education within the context of TAM. Thus, caution needs to be taken when generalizing our findings to other user groups or contexts of use. Second, this study was conducted with a snapshot research approach, so additional research efforts are needed to evaluate the validity of the proposed model and our findings.

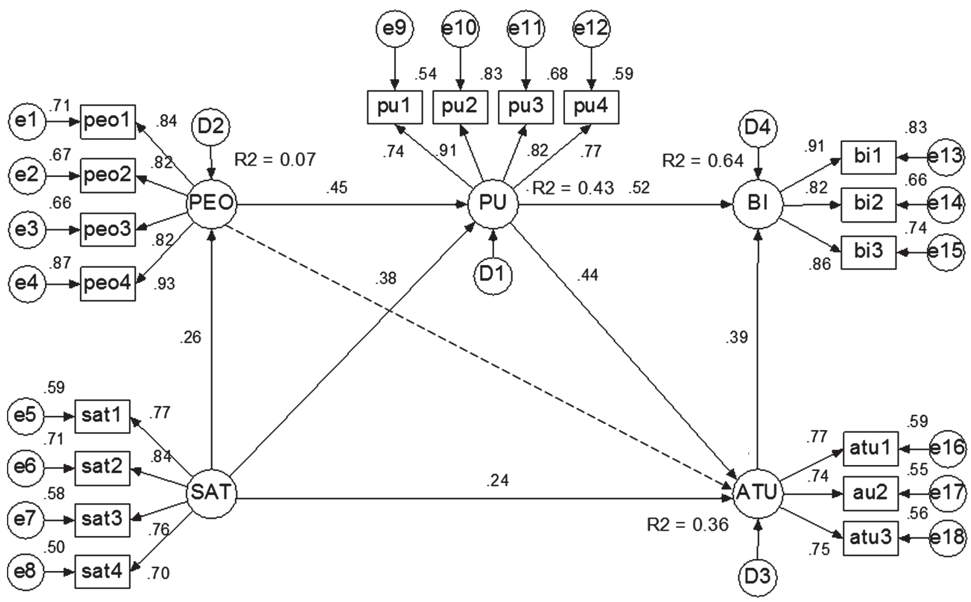

Fig. 6. Integrated model showing standardized estimates. Measured items are illustrated in rectangles (e.g., pu1). Latent variables are illustrated in ovals (e.g., PU); smaller ovals illustrate error of measurement (e.g., e1) and disturbance measures (e.g. D1). Associations are illustrated by arrows that indicate the direction of prediction. Non-significant paths are shown by a dashed arrow. Factor loadings are shown as the outermost value adjacent to item rectangles. Coefficients are noted for each association (i.e., directional arrow). Variance (R2) is noted for each latent variable within the model that has an association directed toward it.

In using a split sample design, with independent samples, there is reasonable external validity. A longitudinal study using a within-subjects design can enhance the understanding of the causality and the interrelationships between variables over an extended period of time, and as reliable usage factors prior to project completion. Finally, the sample size of 170, although large for user testing of research-led systems, is considered small but adequate for SEM research. As technologies become more specialised, it becomes increasingly difficult to gain large samples of representative users, and, when dealing with prototype systems, this is further confounded. Past research suggests that social, organizational, and cultural contexts influence individuals' decisions about technology acceptance. Analysis of cross-cultural effects were not incorporated within this study due to the limited sample size and model parsimony in integrating cultural effects, such as subjective norm. This study did not consider such "social" variables. Future research may seek to study how social norms and existing social practices influence the formation of individuals' attitude in the context of technology acceptance within educational settings and other future interactive systems.

9. CONCLUSION

The contributions of this study are five fold. First, it successfully models affective, motivational and cognitive attitudes and beliefs for users of a prototype system, after an initial use lasting very short time. Second, it provides an adequate interpretation of TAM within an e-learning context, in accurately predicting user intentions for future usage of adolescents. Third, it provides a clear distinction between affective and cognitive attitudes by incorporating a key component of user satisfaction within the TAM framework, and confirms the hypothesised contributions of affect on technology acceptance. In specifying affective response, as a primary component of satisfaction, and suggesting that investigations, whereby users are subjected to novel and innovative technologies, gaining responses geared toward affective reactions is beneficial. Fourth, the study provides empirical evidence suggesting that dimensions of comfort have moderating effects upon user acceptance when applied to wearable technologies, and that gender also plays a moderating role in user attitudes and beliefs. Finally, it shows how such results can be utilised within an iterative design framework for introducing emerging technologies that go beyond the traditional desktop applications used in the majority of TAM investigations.

The results of the study also indicate that ergonomic factors directed towards wearability of future systems have effects on user acceptance, and can differentially influence affective, motivational and cognitive processes. This study postulates usability as a description of the complex inter-relationship between people and technology in evaluating the holistic user experience of technologies within the intended context of use. Furthermore, this study should encourage researchers to widen the scope of acceptance research beyond desktop technologies. Technologies become more ubiquitous within domains such as education, entertainment and the workplace, and their acceptance should be an important consideration for all technological advancements, and wearable technologies. Augmented Reality, as a specific example of wearable technology, is no longer limited to research laboratories, but has been successfully implemented within the workplace of large multinational firms and therefore should be carefully studied to avoid a potential gap between acceptance theory and future interactive systems.

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References and Notes

1. D. A. Norman, *Interactions* 4, 36 **(2002)**.
2. F. Davis and V. Venkatesh, *IEEE Trans. Eng. Manage.* 51, 31 **(2004)**.
3. ISO 9241-11, Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs)—Part 11: Guidance on usability **(1998)**.
4. J. F. Knight and C. Baber, *Hum. Factors* 47, 77 **(2005)**.
5. J. F. Knight, D. D. Williams, T. N. Arvanitis, C. Baber, S. Sotiriou, S. Anastopoulou, and M. Gargalakos, *Proceedings of the 10th International IEEE Symposium on Wearable Computers*, Montreaux, Switzerland, October **(2006)**.
6. R. J. Stone, *Proceedings of the Interservice/Industry Training, Simulation and Education Conference I/ITSEC* Orlando, USA, December **(2004)**.
7. C. Baber, Evaluation of Human Work, edited by J. R. Wilson and N. Corlett, Taylor and Francis, London **(2005)**, pp. 383–415.
8. T. Starner, S. Mann, B. Rhodes, J. Levine, J. Healey, D. Kirsch, R. Picard, and A. Pentland, *Presence* 6, 386 **(1997)**.
9. Y. Argotti, L. S. Davis, V. Outters, and J. P. Rolland, *Comp. Graph.* 26, 919 **(2002)**.
10. R. T. Azuma, *Presence* 6, 355 **(1997)**.
11. S. Sotiriou, S. Anastopoulou, S. Rosenfeld, O. Aharoni, A. Hofstein, F. X. Bogner, H. Sturm, and K. Hoeksema, *Proceedings of the 6th IEEE International Conference on Advanced Learning Technologies*, Kerkrade, The Netherlands, July **(2006)**.
12. J. R. Hill, M. Hwa Koh, E. S. Singleton, and L. Song, *Intern. High. Educ.* 7, 59 **(2004)**.
13. P. Jackson, J. Ealey-Sawyer, I-L. Lu, and S. Jones, *IEEE and ACM International Symposium on Augmented Reality (ISAR'01)*, New York, USA, October **(2001)**.
14. S. Julier, Y. Baillot, M. Lanzagorta, D. Brown, and L. Rosenblum, *Proceedings of International Information Systems Technology Panel (IST) NATO Symposium for New International Processing Techniques for Military Systems*, Istanbul, Turkey, October **(2000)**.
15. W. Lorensen, H. Cline, C. Nafis, R. Kikinis, D. Altobelli, and L. Gleason, *Proceedings of IEEE Conference on Visualisation* San Jose, USA, October **(1993)**.
16. C. Baber, T. N. Arvanitis, D. J. Haniff, and R. Buckley, Interact'99, edited by M. A. Sasse and C. Johnson, IOS Press, Amsterdam **(1999)**, Vol. 1, pp. 126–132.
17. M. Fishbein and I. Ajzen, Beliefs, Attitude, Intention and Behaviour: An Introduction to Theory and Research. Addison-Wesley, Reading **(1975)**.
18. B. H. Shepherd, J. Hartwick, and P. R. Warshaw, *J. Consum. Res.* 15, 325 **(1998)**.
19. F. D. Davis, *MIS Q.* 13, 319 **(1989)**.
20. Y. Lee, K. A. Kozar, and K. R. T. Larsen, *Comm. Assoc. Inf. Syst.* 12, 752 **(2003)**.
21. H. Sun and P. Zang, *Int. J. Hum.-Comput. Stud.* 64, 53 **(2006)**.
22. Y. Malhotra and D. F. Galletta, *Proceedings of the 32nd Hawaii International Conference on System Sciences*, Maui, USA, January **(1999)**.
23. D. Gefen and M. Keil, *ACM SIGMIS Database* 29, 35 **(1998)**.
24. P. Y. K. Chau and P. J. Hu, *Inf. Manage.* 39, 297 **(2002)**.
25. V. Venkatesh and F Davis, *Manage. Sci.* 46, 186 **(2000)**.
26. R. G. Saade, I. Galloway, and J. Molson, Issues in Informing Science and Information Technology, edited by E. B. Cohen, Informing Science Press, Santa Rosa **(2005)**, Vol. 2, pp. 287–296.
27. G. L. Clore, N. Schwarz, and M. Conway, Handbook of Social Cognition, edited by R. S. Wyer and T. K. Srull, Erlbaum, Hillslade **(1994)**, Vol. 1, pp. 323–419.
28. J. Blascovich and J. Tomaka, *Adv. Exp. Soc. Psych.* 28, 1 **(1996)**.
29. J. P. Forgas, *Psychol. Bull.* 117, 39 **(1995)**.
30. P. Zhang and N. Li, *Commun. ACM* 48, 105 **(2005)**.
31. H. Yang and Y. Yoo, *Decis. Support Syst.* 38, 19 **(2003)**.
32. W. J. McGuire, Handbook of Social Psychology, edited by G. Lindzey and E. Aronson, Random House, New York **(1985)**, pp. 233–364.

33. R. P. Bagozzi, *J. Person. Soc. Psych.* 41, 607 **(1981)**.
34. R. McSweeney, SUMI: A psychometric approach to software evaluation, MA (Qual) Thesis in Applied Psychology, University College Cork, Ireland **(1992)**.
35. W. H. DeLone and E. R. McLean, *Inf. Sys. Res.* 3, 60 **(1992)**.
36. I. Ajzen and M. Fishbein, Handbook of Attitudes, edited by D. Albarracín, B. T. Johnson, and M. P. Zanna, Erlbaum, Mahwah **(2005)**, pp. 173–220.
37. D. L. Goodhue, *ACM SIGMIS Database* 19, 6 **(1998)**.
38. N. Melone, *Manage. Sci.* 36, 76 **(1990)**.
39. G. Borg (ed.), Physical Work and Effort, Pergamon, New York **(1975)**.
40. J. P. Chin, V. A. Diehl, and K. L. Norman, *CHI '88 Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, Washington, DC, USA, May **(1998)**.
41. S. L. Crites, L. R. Fabrigar, and R. E. Petty, *Person. Soc. Psych. Bull.* 20, 619 **(1994)**.
42. F. J. R. van de Vijver and K. Leung, Methods and Data Analysis for Cross-Cultural Research, Sage, Thousand Oaks **(1997)**.
43. J. Nunnally and J. Bernstein, Psychometric Theory, McGraw Hill, New York **(1994)**.
44. P. M. Podsakoff, S. B. MacKenzie, J.-Y. Lee, and N. P. Podsakoff, *J. Appl. Psychol.* 88, 879 **(2003)**.
45. C. Fornell and D. F. Larcker, *J. Market. Res.* 18, 39 **(1981)**.
46. L.-T. Hu and P. M. Bentler, *Struct. Equ. Modeling* 6, 1 **(1999)**.
47. D. A. Adams, R. R. Nelson, and P. A. Todd, *MIS Q.* 16, 227 **(1992)**.
48. J. Arbuckle and W. Wothke, AMOS 4.0 User's Guide, Smallwaters Corporation, Chicago **(1999)**.
49. C. S. Ong and J. Y. Lai, *Comp. Hum. Behav.* 22, 816 **(2006)**.
50. L. Shashaani and A. Khalili, *Comput. Educ.* 37, 363 **(2001)**.
51. B. E. Whitely, *Comp. Hum. Behav.* 13, 1 **(1997)**.
52. S. T. Fisk and L. E. Stevens, Gender Issues in Contemporary Society, edited by S. Oskamp and M. Costanzo, Sage, Newbury Park **(1993)**, pp. 173–196.
53. J. Long and A. Dowell, People and Computers, edited by A. Sutcliffe and L. Macauley, Cambridge University Press Cambridge, Cambridge **(1989)**, Vol. 5, pp. 9–34.
54. W. W. Chin and P. A. Todd, *MIS Q.* 19, 237 **(1995)**.
55. P. E. Meehl, *Psych. Rep.* 66, 195 **(1990)**.
56. B. H. Wixom and P. A. Todd, *Info. Sys. Res.* 16, 85 **(2005)**.

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