Software Learnability Evaluation

An Overview of Definitions and Evaluation Methodologies for GIS Applications

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***Abstract*— Learnability has been regarded as an important aspect of usability and considered a fundamental usability attribute. Yet, learnability is often overlooked as one of the most influential factors for the success of software applications especially Geographic Information Systems (GIS) applications. GIS Applications have seen a tremendous development during the last decades. Becoming more advanced, the amount, diversity and high turnover demand fast learning from users. Good learnability not only leads to a better productivity quickly but also plays a vital role in initial adoption or rejection of a technology. There are numerous approaches used to define, measure, and evaluate learnability. This paper presents some previously researched definitions along with methodologies for learnability evaluation with a special focus on desktop GIS applications. Our survey of definitions and evaluation methodologies leads us to a conclusion that there is a need of further research for a sound and widely accepted methodology for learnability evaluation of GIS applications.**

Keywords - learnability; GIS applications; learnability evaluation; learnability in use; usability.

I. INTRODUCTION

With the pervasiveness of the software in our everyday lives, the need for quality software systems becomes indispensable. Evaluating and improving quality needs a process of continuous assessment. This evaluation should be based on various functional as well as nonfunctional properties. Non-functional properties as depicted by ISO 25010 [5] such as efficiency, learnability, security, reliability and attractiveness, amongst others, all contribute appreciably to the quality of software systems.

In the last decade, there has been a rapid increase in the use of Geographic Information System (GIS) applications, especially web-based GIS applications (GISApps), in fields like education, transport, criminology, marketing, sociology, business and disaster recovery. Today almost all businesses and government agencies use GISApps as a tool for decision making and problem solving.

Learnability, by some definitions, characterizes how easy is it for users to accomplish basic tasks the first time they encounter the software application. In an increasingly technological world, software, especially GISApps, are becoming more varied and complex. New features are being added quite rapidly to new GISApps, which users are expected to use immediately. The learnability of modern GISApps, especially web-based GISApps, has a distinctive importance. With conventional software systems, users must make an investment (often substantial) in time and effort to install and learn to use an application. However, with web-based applications, users can very quickly switch from one Web application to another with minimal effort. In 2006, Lazar et al. [10] discovered that users reported wasting on average, 42-43% of their time on the computer due to frustrating experiences. When looking at the specific causes of the frustrating experiences that occurred, the study found error messages and missing/hard to find/unusable features were among top five causes closely related with poor usability and more specifically poor learnability. Good learnability will lead to reasonable learning times, adequate productivity during the learning phase, and thus better satisfaction in new users. Improving learnability, thus, has a significant impact on the success of software applications and especially for GISApps, as GISApps involve a different interaction style, three dimensional interface designs and the need of grasping spatial concepts, making them more difficult to learn. But, improvement first requires identifying and understanding learnability issues. Also, learnability issues can only be exposed by clearly defining, and then evaluating it in systematic and consistent way.

Although researchers recognize the importance of learnability, the consensus among researchers regarding defining and evaluating learnability seems lacking, leading to the conclusion that software systems still pose learnability problems. The main objectives of this research are to: 1. Understand learnability in detail with respect to GISApps and the special characteristics of GISApps that need consideration. 2. Analyze the related research in learnability evaluation with reference to GISApps. Although GISApps are being widely utilized in different devices like desktops, mobile devices and cellular phones, etc., this research is focused on learnability related to desktop applications only.

Following this introduction, Section II provides background on state of the art research in learnability. Section III highlights the importance of learnability for GISApps. Section IV provides evaluation schema for learnability with respect to GISApps. The subsequent section emphasizes quality in use (QinU) aspect of learnability and Section VI concludes the paper and outlines future work.

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II. Characterizing Learnability

This section of the paper provides background on learnability while examining the existing research and delineating areas for improvement regarding clarity in its definition.

A. Definiing Learnability

In order to evaluate learnability, first we have to define and understand it clearly. There have been a number of different definitions proposed. Table I summarizes some of these definitions. The tabulated definitions are among the many different definitions used by different researches over the last two decades. For the purpose of brevity we have only included representative definitions involving some unique types of measures in defining learnability.

Nielsen [1], Holzinger [19], Shneiderman 1995 [20], and Chapanis [21] define learnability in terms to time that is how quickly users learn to operate the software. Dix et al. [3] and Stickel et al. [22] define learnability in terms of ease with which new users can begin effective interaction with the system. Santos and Badre [6] define learnability in terms of measure of effort required to achieve a defined level of proficiency. Hart and Steveland [8] and Linja Aho [23] define learnability in terms of time and ease with which user starts efficient interaction with the product. Rieman [24], Butler [13] and MUMMS Questionnaire [25] define learnability in terms of user performance without formal training. Ziefle [26] and ISO 9126-1 [16] define it in terms of software product properties that enable user to learn its application. Hart and Steveland [8], Kirakowski and Claridge [4] and MUMMS Questionnaire [25] highlight subjective aspects of learnability by judging it from user's feelings about learning process. Most of the definitions refer to the performance of user relevant to their first interaction with the software (initial learnability), but some researchers have also taken note of extended learnability, that concerns improvement in performance over time ([3][4][11][13]). Extended learnability or advanced learnability has been characterized by learning of new or advanced features, ability to adoption alternate model that involved fewer screens or keystrokes, ability to master the software and ability to achieve maximal performance. This description clearly shows the diversity in the use of measures among researchers regarding defining learnability.

TABLE I. Summary of Learnability Definitions

No.	Source	Definition
1.	Jakob Nielsen (1993) [1]	Novice user's experience on the initial part of the learning curve.
2.	Dix (1998) [3]	Ease at which new users can begin effective interaction and achieve maximal performance
3.	Santos and Badre (1995) [6]	Measure of the effort required for a typical user to be able to perform a set of tasks using an interactive system with a predefined level of proficiency.
4.	Hart and Steveland (1988) [8]	The speed and ease with which users feel that they have been able to use the product or as the ability to learn how to use new features when necessary.
5.	Bevan and Macleod's (1994) [11]	A measure of comparison the quality of use for users over time.
6.	Butler (1985) [13]	Initial user performance based on self instruction" and "[allowing] experienced users to select an alternate model that involved fewer screens or keystrokes.
7.	Kirakowski and Claridge (1998) [4]	Within the web context is the degree to which users feel able to manage the product's basic functions during its first use.
8.	ISO 9126-1 (2001) [16]	The capability of the software product to enable the user to learn its application
9.	ISO 25010 (2011) [5]	Degree to which a product or system can be used by specified users to achieve specified goals of learning to use the product or system with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use

Grossman et al. [27] carried out a survey of 88 research papers related to learning in HCI (Human Computer Interaction), 45 discussed learnability without a definition, and the remainder had conflicting definitions. They classify learnability definitions in eight different categories. Instead of deciding upon a common definition, they developed taxonomy of learnability definitions after highlighting the short comings in current definitions. Key features of the developed taxonomy include the existence of an optimal performance level, the dimension of experience, and the timeline of when the learning takes place.

In general terms "*learnability is a characteristic where performance improves with experience. As tasks are repeated, elements of the task are better remembered, prompts are more clearly distinguished, skills are sharpened, transitions between successive tasks are smoothed, eye-hand coordination is more tightly coupled, and relationships between task elements are discovered. The aggregation of these effects results in faster performance times, fewer errors, less effort, and more satisfied users*" [28].

B. Software Quality perspectives of Learnability

ISO quality models can be used to support specification and evaluation of software from different perspectives by those associated with acquisition, requirements, development, use, evaluation, support, maintenance, quality assurance and audit of software. The ISO 25010 [5] defines

1) A quality in use (QinU) model composed of five main characteristics (Effectiveness, Efficiency, Satisfaction, Freedom from Risk and Context Coverage) that relate to the outcome of interaction when a product is used in a particular context of use.

2) A product quality model composed of eight main characteristics (including usability) that relate to static properties of software and dynamic properties of the computer system.

Many researchers ([1][2][3]) and standards (IEEE standard 610.12 [29], ISO 9126-1 [16] and ISO 25010 [5]) have mentioned learnability as an important attribute of usability. In ISO 9126 the product centered view of usability and learnability was presented but in recent standards both products centered and QinU centered views have been presented. According to guidelines of ISO [5], learnability can be specified or measured in two different ways. The first one is the "*extent to which a product or system can be used by specified users to achieve specified goals of learning to use the product or system with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use*". This corresponds to QinU aspect of learnability. We further discuss this aspect in more detail in Section V. The second method of specification and measurement of learnability is by product properties corresponding to suitability for learning as defined in ISO 9241-110 [30]: *"software product quality is the cause and QinU is the effect"*. Thus learnability can be seen as *the collective effect of key product attributes that lead to efficient and effective learning of a software product with high end user satisfaction levels in a specified context of use*.

III. GIS Applications and Learnability

This section depicts specific characteristics of GISApps, which put greater emphasis on learnability of GISApps.

Although GISApps work in a graphic user interface, they are quite different from general computer applications. The special functions required to manipulate spatial aspects make the interface complicated and difficult to learn. To make matters worse, GISApps employ unique interfaces, and therefore users must learn a different interface style with each application. GISApps generally require three dimensional (3D) interaction styles. Although we live and act in a 3D world, the physical world contains many more cues for understanding and constraints and affordances for action that cannot currently be represented accurately in a computer simulation. It is quite difficult for new users to transform traditional WIMP (Windows, Icons, Menus, Pointers) interaction styles to three dimensional interaction, leading to learning difficulties.

A GISApp combines query functions and analysis with visualization and geographic features to examine spatial problems. Using, managing, and analyzing spatial data, and enabling a user to analyze spatial questions is distinctive to GISApps, but this leads to usability issues especially in understanding and learning the application. For GISApps, users have a relatively long learning curve due to the need to grasp geographical concepts and different data types. Also, the level of user knowledge of geographical concepts, and task dependency on geographic concepts are special considerations [31]. A report on the Leonardo Pilot Project, E-GIS (about learning of GIS applications) notes difficulty in learning of GISApps as one of the main causes of student drop out during learning course [32].

In addition to different interaction style, GIS visualization poses several challenges. GIS employ a virtual environment (VE) to display and interact with high dimensional geospatial structures and phenomena. Way-finding in such an environment has certain challenges. In the real environment, kinesthetic feedback is available to the user; movement is restricted by physical boundaries. In VE such feedback is not normally given. Navigation in VE is generally controlled indirectly with interaction tools such as keyboard, mouse, joysticks, etc. Since desktop VEs are seldom immersive, navigation in such a VE is even less similar to real world navigation because navigation in addition to being indirect is typically controlled from the "outside" of the environment (like controlling a toy car by remote control) [33]. It is therefore common for a novice user losing orientation (awareness of the space around, including the location of objects and places) during way-finding process.

GIS displays wide regions on a small screen and allows navigation in large spaces. Unlike the bird's eye, overall view map of an area, the user often deals with only a part of a large scale space (not visualized entirely from one viewpoint). It is common for the novice users to get "lost" when zoomed into a small area without reference text (e.g., place names).

In current era of GISApps, learnability has new challenges as software is mostly released online and online help and support are the main customer support mechanisms. Therefore, the existing research in software learnability needs appropriate considerations specifically for GISApps.

IV. Learnability Evaluation

The previous section discussed some of the particular characteristics of GISApps and the importance of requiring a new model for learnability evaluation. This section examines some of the existing methods for evaluating learnability for GISApps.

Usability engineering research literature mentions several usability evaluation methodologies; however, their suitability for evaluating learnability is not well elaborated. Similarly the suitability of methodologies used for non GISApps for GISApps is also not very obvious. We discuss only those methodologies in this section which have been used for evaluation of GISApps.

One of the most common forms of usability testing is the "Think-Aloud Protocol". In this technique respondents are asked to give a verbal account of their thinking as they answer (concurrent) or immediately after answering (retrospective) a draft survey question [25]. Komarkova et al. [34] employed Think Aloud Protocol to find usability problems in 14 Web based GISApps run by the Czech Regional Authorities. They identified learnability related issues like complexity of search tools and lack of interface understandability. Nivala et al. [35] used this methodology to identify the potential usability problems of web mapping sites, including learnability issues like interface crowdedness, lack of conformity to user expectations and absence of map legends, etc. Think Aloud technique provides rich qualitative data and allows first hand insight into the thought processes associated with different tasks. Think Aloud methodology can be useful for identifying learnability issues, but takes place in the unnatural environment of a usability lab [3]. Moreover, people can only report what they are aware of and can report about the components of high level mental processes, like the sequence of steps that leads to the solution of a problem. Furthermore, it is difficult to identify changes in behavior due to learning by this method.

Focus Group [1] is another methodology in which a number of users are brought together to discuss new concepts and identify issues over a certain period of time. Each group is run by a moderator who is responsible for maintaining the focus of the group on whatever issues are of interest. Fuhrmann and MacEachren [33] employed Focus Group for the evaluation of a geovirtual environment and discovered many learnability issues like lack of predictability, difficult to find features, lack of informative feedback from software etc. Harrower et al. [36] employed Focus Group to assess an animated and interactive geovisualization environment Earth System Visualizer and implications of this environment for learning about spatiotemporal processes. They deduced that novel interfaces may not result in improved performance unless sufficient training is provided on how to use them. Focus Groups usually provide immediate ideas for the improvement of particular products or concepts. This method can be useful for identifying learnability issues and proposal of design guidelines, but it is rather subjective and expensive methodology. Moreover Focus Groups are not efficient in covering maximum depth on a particular issue. Additionally moderator bias can greatly impact the outcome of a Focus Group discussion.

For the evaluation of MapTime, a software package for exploring spatiotemporal data associated with point locations, Slocum et al. [37] employed a methodology consisting of a combination of individual interviews and Focus Groups conducted for three distinct groups of participants: novices, geography students, and domain experts, and discovered that individual interviews are particularly useful in obtaining users' reactions to software (as opposed to having them learn the software on their own) because the interviewer can steer the interview based on the user's responses.

Observation is a quite frequently employed method for learnability evaluation. It involves visiting one or more users in their workplaces. Notes must be taken as unobtrusively as possible to avoid interfering with their work [19]. Video recording has also been a very frequently used method for observational data collection. Jones et al. [38] used video analysis for an exploratory task-orientated project workshop with the four project team members, for usability and learnability evaluation of a geographic profiling tool. They measured learnability by video analysis of users' browsing interaction. Hossain and Masud [39] used video evaluation to evaluate "ArcView" GIS software with four participants during two hours of interaction. They found 12 learnability problems using this method including interface understandability, presence of unfamiliar terms, help and error messages inadequacy etc. Video recording is quite comprehensive way of data collection, but analysis required is quite time taking.

Another means of electronic observation is Data Logging, which involves statistics about the detailed use of a system. Meng and Malczewski [40] used a data logging approach to evaluate usability and learnability of a public participatory GISApp named ArgooMap. The users' every move on the website was recorded with a logging software which made it possible to obtain detailed and useful information about the actual usage of the website holding ArgooMap. Although this methodology captures data automatically, it has not been widely applied for learnability evaluation in GISApps.

Lew et al. [41] used C-INCAMI (Contextual-Information Need, Concept model, Attribute, Metric and Indicator) framework to evaluate learnability as a product characteristic of a GISApp named Chinastar. C-INCAMI is a framework which relies on an ontological conceptual base; on a well-established measurement and evaluation process. Using this methodology some learnability issues like lack of predictability were identified. This methodology is model based and provides quantitative results, but there seems to be involvement of subjective judgments while computing the metrics for learnability attributes.

Some researchers employed a combination of several methodologies for investigating different aspects of usability of GISApps. Nivala et al. [35] for example, conducted a series of expert evaluations and user tests. During the expert evaluations, eight usability engineers and eight cartographers examined the web based GISApps including Google Maps, MSN Maps and Directions, MapQuest, and Multimap, by paying attention to their features and functionality. Additionally, eight user tests were carried out by ordinary users in a usability laboratory. User tests used a combination of Think Aloud and video recording method. Kristoffersen [42] used a "traingularization" of observation, interviews and document study to evaluate usability of ArcView used for viticulture purposes and concluded that the user consider learnability and functionality aspects to be top usability issues.

Many aspects of usability can best be studied by querying the users. This is especially true for issues on the subjective satisfaction of the users and their possible anxieties, which are hard to measure objectively. Use of a subjective questionnaire has been a very effective and popular method for usability evaluation. Being a sub characteristic of

TABLE II. STATISTICS OF LEARNABILITY RELATED QUESTIONS IN FAMOUS QUESTIONNAIRES

Questionnaire Name	Number of Questions	
	Product Perspective	***QinU Perspective***
Purdue Usability Testing Questionnaire (PUTQ) [2]	34	-
Software Usability Measurement Inventory (SUMI) [4]	4	6
Questionnaire for User Interaction Satisfaction (QUIS) [7]	7	10
The Post-Study System Usability Questionnaire (PSSUQ) [9]	2	2
Practical Heuristics for Usability Evaluation (PHUE) [12]	5	-
SUS (System Usability Scale) [14]	-	4
IUI (Isometrics Usability Inventory) [15]	11	6
WAMMI (Website Analysis and MeasureMent Inventory) [17]	-	2
Usefulness, Satisfaction, and Ease of use. (USE) [18]	-	4

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usability, learnability has also been evaluated by using subjective questionnaires. Table II lists some famous questionnaires along with number of questions relevant to product oriented and QinU oriented aspects of learnability.

It must be kept in mind that the software learnability evaluation should provide quantitative or qualitative results that are comprehensible, acceptable and repeatable, in order to prove a key driver for improvement in learnability and consequently in software quality. All referenced methodologies require users to either identify learnability problems or evaluate subjective or objective learnability by measuring time on task, task correctness, error counts or user's subjective responses. Most approaches are not model based and seem to be not easily reproducible. ISO 25010 and ISO 9126 both treat learnability as a product characteristic that is a characteristic of internal or external quality. However, there has been a limited effort regarding evaluating learnability from product quality perspective [31].

Think Aloud Protocol, Focus Group, and interviews are all quite direct methodologies for learnability issues identification, but have some limitations. These methodologies are prone to high level of subjectivity as well as the interplay of a legion of factors, including the characteristics of the users, the environment, the sample size of the user group, etc., leading to problems in isolating individual factors under examination. Similarly data logging method has not been found to be widely applied for GISApps. C-INCAMI, seems to be a model based scheme but has some subjective judgments involved for producing quantitative results. Moreover, its applicability in GIS domain has been very limited.

V. QULAITY IN USE ASPECT OF LEARNABILITY

As mentioned in Section II-B, learnability has been considered as an attribute of usability. There has been an inconsistency even within ISO software quality model regarding concept of usability. In earlier drafts of ISO 9126, usability was defined primarily in terms of product attributes as "*A set of attributes of software which bear on the effort needed for use and on the individual assessment of such use by a stated or implied set of users*". In ISO/IEC CD 25010.3 [43], the product centered view of usability as presented in ISO 9126 was deemed narrow at that time and renamed as operability but in its final release ISO/IEC 25010:2011 it was retained as usability. In ISO/IEC CD 25010.3, usability appeared as a characteristic of quality in use. The recent ISO 25010 standard, regarding usability evaluation states, "*Usability can either be specified or measured as a product quality characteristic in terms of its sub-characteristics, or specified or measured directly by measures that are a subset of quality in use*". We argue that users achieve their intended goals with effectiveness, efficiency, satisfaction and freedom from risk (the sub characteristics of QinU) not only because of usability, but also due to other product quality characteristics like utility (e.g., right functionality or functional suitability), reliability and performance efficiency etc. The usability attributes of a product are thus only one contribution to the quality in use of an overall system. It is, therefore worthwhile to model "in use" part of usability on QinU model side, rather than considering it as a total "in use" aspect of usability. Being a sub characteristic of usability, learnability can further be modeled on QinU side also. Based on our thorough analysis of literature and questionnaires we have noticed several sub characteristics of learnability that can be incorporated in QinU model. Lew et al. [41] has already mentioned learnability in use concept defining it as "the degree to which specified users can learn efficiently and effectively while achieving specified goals in a specified context of use". Most of the learnability evaluations mentioned in Section IV measure QinU aspect of learnability without defining it specifically as such. In true model based evaluation methodologies both aspects of learnability vis-a-vis product centered and QinU oriented should be considered.

VI. CONCLUSION AND FUTURE WORK

Learnability has an increased importance for GISApps because of the need of grasping spatial concepts and different interaction styles. In learnability research, there has been inconsistency in defining learnability and treating it as product characteristic or QinU characteristic. There have been numerous evaluation methods developed and used by researchers during past years, but there seems to be a lack of consistency and cross verification between evaluated results. Although some researchers have developed methods to evaluate learnability in more organized, conceptual and model based ways, their applicability in GIS domain is quite limited. There is a need to further strengthen the area of learnability evaluation in GISApps domain. More research, thus, needs to be done for a sound and widely accepted learnability evaluation methodology for GISApps.

In the future, we will develop a comprehensive evaluation methodology for modeling and evaluation of learnability of GISApps. As a first step we are developing a comprehensive concept model that can be employed for evaluating evaluate GISApps.

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