Study on contexts in tracking usage and attention metadata in the field of multilingual Technology Enhanced Learning

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Abstract: In order to exploit usage and attention metadata, one needs to define what properties of usage to use and why, second, how to gather data on that property, and third, what to do with that information. In this paper, we propose to consider usage and attention metadata as an example of the wider notion of *context* and give an overview of dimensions of context that are relevant in technology enhanced learning (TEL). We consider the intersection of the areas of digital learning resource repositories, digital libraries, and other Web environments including social tagging systems. Specifically, we argue that context comprises the usage situation and environment as well as persistent and transient properties of the user. Therefore, we distinguish between the macro-context and the micro-context of TEL. We further subdivide the latter into user models, material/environment models, interaction models, and background knowledge, showing that usage and attention metadata are of different types and play different roles for learning about context. We then concentrate on teachers using learning-resource repositories as an important use-case example of TEL and focus on language and country as context variables. We describe different ways in which these variables can be measured, i.e., ways of operationalising the construct and data gathering to provide values for the variable. Finally, we outline how TEL can use such context information to improve the use and reuse of repositories by making them more useful in a multilingual and multicultural context. A key theme of our article is the central role that *social tagging* can play in this process: on the one hand, tags describe usage, attention, and other aspects of context; on the other hand, they can help to exploit context data towards making repositories more useful, and thus enhance the reuse.

1 Introduction

"Context" is widely accepted to be important for correctly interpreting user input and to improving predictive and possibly also diagnostic models. But what is context, and how can it be measured? In this study, we consider the intersection of the areas of digital learning resource repositories, digital libraries and social tagging systems. Users and the usage of different systems in these fields have been studied by different means, such as using Data mining techniques, e.g. [RV07]; Web metrics, e.g. [KPW+08], [Och08];

attention metadata, e.g. [WNVD07]; or more mixed and qualitative methods, e.g. [HHN06], [PNJK08]. We argue that their methods for studying users, usage and context are in many cases comparable or complementary, and that studying these different but converging contributions to the operationalisation and measurement of context can benefit all of these areas. The purpose of our paper is to stimulate discussion on how technology enhanced learning (TEL) could profit (more) from previous or parallel approaches to context measurement.

In order to gather data about users' information and communication needs and to serve these needs better, determining the context is important. "Context" itself is a contested term and defined differently in fields such as AI, software agents, HCI, ubiquitous computing, and others (see [Sch02] for an overview). We treat context as "any information that can be used to characterise the situation of entities" [Dey01] and use the common differentiation between (a) environment (e.g. location, time, weather, other properties of the physical environment or computational infrastructure), see [LS00], and (b) persistent or transient properties of the user (trait and state variables) such as the social environment, preferences, or task, e.g. [WK89, LS00].

Dey's [Dey01] definition in particular illustrates that a wide range of things may count as context, a point that has been confirmed by other authors, cf. [Sch02]. What effectively counts as context will always depend on the domain and the analysis question. For example, while fine-grained geographical coordinates are relevant for location-based services such as restaurant finders (and retrievable with current ubiquitous-computing technology), such information is irrelevant for most uses of learning resource repositories – in contrast to the more coarse-grained information on country, which may give important clues regarding the regional or national curriculum alignment that a user (e.g. teacher) is likely to be interested in.

The paper is structured as follows: We start by elaborating on different macro-contexts in TEL and then proceed to analyse micro-context in terms of parameters of interaction, user models and background knowledge for better measuring context. We then give examples of the field on on-going research work and finally Section 5 gives a conclusion for the paper.

2 Macro-context in Technology Enhanced Learning

TEL and the analysis of the data it generates take place in different types of educational settings which we call the *macro-context* of TEL. It generally has significant influence on what user actions are possible and how they can be interpreted. In this section, we give an overview of main dimensions of macro-context such as educational level, formal and informal learning [CHM02], delivery setting and different user roles. This list is not exhaustive.

Examples of the *educational level are* K-12 education, Higher Education (HE), Vocational Education and Training (VET), workplace training. A *formal setting* for learning includes learning offers from educational institutions (e.g. universities, schools) within a curriculum or syllabus framework, and is characterised as highly structured, leading to a specific accreditation and involving domain experts to guarantee quality. This traditionally occurs in teacher-directed environments with person-to-person interactions, in a live and synchronous manner.

An *informal setting,* on the other hand, is described in the literature as a learning phase of so-called lifelong learners who are not participating in any formal learning context and are responsible for their own learning pace and path [Lon03]. The learning process depends to a large extent on individual preferences or choices and is often self-directed [BH91]; [Lon03] . The resources for informal learning might come from sources such as expert communities, work context, training or even friends might offer an opportunity for an informal competence development.

The TEL involvement can be characterised by the provision of blended learning opportunities to purely distant educational ones [Moo03]. Blended learning combines traditional face-to-face learning setting and computer-supported learning [Gra05]. Distance education, on the other hand, can be delivered using TEL environments in either synchronous or asynchronous ways. Traditionally, distance learning was more related to self-paced learning and learning-materials interactions that typically occurred in an asynchronous way [Gra05]. However, live streaming and virtual, personal learning environments (e.g. Web 2.0) have facilitated the development of synchronous distant learning services in formal educational settings.

Lastly, different *actors* and *needs* can be identified in TEL. A distinction can be made between the teacher-directed interaction and learner-directed learning processes. This has ramifications concerning the *intended users* of TEL environments.

While macro-context has large implications for interpretation and design, its aspects are fairly agreed-upon, and it is comparatively easy to measure. Micro-context is a more contested notion and more difficult to measure. However, while macro-context is domain-specific, concepts for micro-context range over more diverse fields.

3 Micro-context: usage and user attention at the intersection of digital repositories and social tagging

We use the term *micro-context* to denote the context that is relevant for interpreting a specific user input (e.g. a search term) and for designing adequate system responses and other system output. Micro-context may be provided by the activities themselves, the user (model), or further background knowledge, often referring to the material. In each case, the question arises how to measure these variables. We will illustrate answers through exemplary studies including our own current work. This extends a previous comparison of converging context representations in knowledge discovery/web mining, user modelling, and TEL [Ber07].

For many types of (meta)data available in electronic environments, it is rather straightforward to determine whether they relate to activity, user, or material. Tags are

an interesting exception: At first sight, a tag may be thought of as just another feature of the material. However, this view ignores the essential role of the user in tagging. Tags and the resulting networks (folksonomies) are commonly modelled as tri-partite hypergraphs, e.g. [CSB+07]. This means that they are formed by triples of (user,item,tag). For analyses, this ternary relational structure is often projected to a lower-dimensional space. This gives rise to (item,tag) relations that – for our purposes – allow tags to be part of the material as context. By looking at the (user,tag) relation, one obtains tags as part of user models – which may for example be leveraged to infer preferred language(s) of the user (Section 3.2). Additionally, an investigation of the (user,item) relation can give important clues to the user's content preferences. The full relational structure emphasises that tags may also be regarded as a parameter of the interaction between a user and an item (Section 3.1).

3.1 Interaction as context – parameters of interaction for measuring context

This view of context regards a user action that is an interaction with a material as an atomic unit of analysis (such as clicking a hyperlink, giving an answer in a multiple-choice question, or downloading a document). This action is associated with certain parameters/metadata: *date and time* including access time and dwell time; *action type* such as download, insertion, viewing; *query terms*; *IP address; operating system, browser* and further technical characteristics of hardware and software; the *application* or tool used including its name, URI, type such as LOR or LMS (e.g. [NWD06]; [BM06]). We call such information "implicit interest indicators" because it is collected non-reactively [CLWB01].

In contrast, "explicit interest indicators" are derived from users (more) consciously expressing their interest in resources. Explicit interest indicators include tags, ratings, and bookmarks. They can give rise to metadata describing the *user's/learner's perspective* on the LO including feedback on the content or knowledge of the content. Both implicit and explicit interest indicators can be regarded as atomic, or in the context of a complex activity such as a session or search episode (which may be a sequence of atomic interest indicators with different values). We first describe the atomic versions and subsequently their use in activity structures.

3.1.1 Atomic implicit interest indicators

Attention metadata in the TEL context for enriching the metadata regarding learning resources in LOR and LMS are studied in [NWD06]. The idea is to capture the attention metadata about the user's actions across system boundaries to enable better targeted personalisation of learning services (e.g. Recommender systems). The authors propose a Contextual Attention Metadata framework that is based on the exchange of information using an extended version of AttentionXML.

[WNVD07] complement the concept of tracking user's attention (e.g. when, how long, in what sequence have this taken place) across applications that are used regularly in TEL (e.g. Office Suite, Web Browsers, Mail Clients). The authors suggest that contextualised attention metadata schema enables the correlation of the observations,

thus reflecting the relationships that exists between the user, her context and the content she works with better. This type of concept seems important especially for informal learning, where learning rarely takes place using institutionalised learning platforms or learning management systems. [KPW+08] investigated the use of session length (derived from the times of the session's clicks) as a metric for digital-library site performance. They report that this metric can be very misleading in the context of digital libraries (as opposed to e-commerce), as the relationship between session length and web site quality is a contextual relationship; for some sites, short sessions might be indicators of quality; while for other sites long sessions might be indicators of quality.

3.1.2 Atomic explicit interest indicators, in particular tags

[CSB+07] found that folksonomies are highly connected and that the relative path lengths are small, which facilitates the "serendipitous discovery" of new content and other users. Tags have therefore become popular as clear-cut indicators of interest and a basis for recommendation. For example, [SNRI08] track user attention in collaborative tagging communities for academic papers in order to harness usage patterns to improve navigability in a growing knowledge space. They find a clear segmentation of interests into a significant number of small sub-communities of interests that are totally separated from each other and further suggest methods for building efficient, online recommendation systems for tagging communities.

3.1.3 Activity structure

Actions generally do not take place in isolation, but in sequences or parallel threads. When previous or parallel other actions provide information for interpreting an action A, we say that the activity structure provides context (for A). Implicit relevance feedback provided by click data on a university document search system was studied in [JHW07]. They found that considering all the click data in a search session as relevance feedback can increase both precision and recall, however, for high precision, focusing on last visited documents could be more useful.

[SNCNR09] focused on individual and social behaviour in tagging systems. They show that individual need for organising content is a stronger motivation for tagging than collaboration with others to categorise the content. They also found low reuse of previously tagged items which leads to sparse datasets. However, they conjecture that the lower segmentation of tag-based interest sharing allows for content discovery, thus leveraging pair-wise tag-item comparison rather than user-item. Similar finding have been reported by [VPK09] who compared over 20,000 tag applications from five different educational-content platforms. The authors showed that 30% of tag applications overlap through a tag in two or more content platforms, which allows for the discovery of content across platforms.

[VK9b] focused on using attention metadata produced from users' interactions within a learning resources repository where they search, play, rate and bookmark learning resources. The following events had been recorded: session, search (different kinds), click (LO, tag, rating, user), bookmark, tag, rating. These were used to model how users behave on the portal, how they search in different ways (e.g. using conventional search or community browsing using tags), what do they click on and how do they find relevant resources. Moreover, the attention captured from users was used to calculate user's efficiency in using different search methods. It was found that users spent less search effort and clicks to find relevant resources using "community browsing" and social information from other users.

3.2 The user as context – user models for recording context

As argued in the previous Section, tags and other explicit interest indicators can give much information about a current action, and their re-use can be part of models of activity structure. Aggregations over tags created by one user in different activities may also give more "persistent" information about that user. [AYGS08] and [MC07] studied how user modelling can take advantage of personal tags and tagging data in general. [AYGS08] conclude that the majority of users of tagging systems posses multiple interests and propose a way to reflect that in user profiles. and [MC07] base their user model on tagging behaviour for the reason that it can adapt over time.

[VK9a] used bookmarking and personal Collections of digital learning resources as a proxy for the use and reuse of digital learning resources across national and language boundaries. For each user in question, the country of origin and mother tongue were considered, and compared to the country of origin or language of the learning resource that they had bookmarked. This method was used to measure the use and reuse in different contexts, i.e. across boundaries. The authors confirmed previous studies that the reuse within the systems was rather low (around 20%) and that it correlates strongly and significantly with the reuse across national and language boundaries, which was even lower.

Country and language

Country and language may be operationalised in different ways depending on the domain and the analysis questions. Country of birth and mother tongue are essentially persistent user traits, whereas the country a user works in as well as preferred languages may be persistent or transient traits. [VK9a] studied the use of learning resources in repositories where the country in which the user (e.g. teacher) works was used to infer certain features of the resource (e.g. how well it could be used in a new context, alignment with national curriculum). Knowing whether the user accesses information in a first or in a second language – irrespective of the language itself – leads to an operationalisation of language as a variable depending on the relation between user and material [BK09]. In [VK9a] the user variables country and language were given by self-profiling information. These variables may also be inferred from the automatically measured logfile variable IP address. For example, in [BK09] it was used for an investigation of the effects of language on usage behaviour and attitudes towards a

content portal. Further possible clues are the browser settings (self-profiling); the language of the currently used interface where the service is available in different languages; and the language of search terms and tags (user input). For the latter, however, recognising the language is a challenge, as usually only one or a few terms are used. A language classifier taking advantage of dictionaries can be used to predict the likely language of a user input. Additionally, information given by using the other above methods have been investigated in [VO09]. In social tagging systems, for example, the known or inferred languages of tagged resources can give further hints as to the user's preferred language(s).

3.3 Background knowledge, especially related to the material, as context

Background knowledge is pre-existing knowledge about materials, users, etc. An example in TEL is the use of Semantic Web techniques for interpreting an action by [BM06]. They formulate cognitive-behavioural models in RDF, combine a domain ontology (of the topic domain to be learned) and an educational objectives ontology. The Semantic Web architecture allows a flexible association of data on usage with such background models of leaner behaviour and competencies.

Standard, expert-provided background knowledge may also be enriched by tagging. [VSPK09] studied tags for the purpose of enriching existing metadata of educational resources in a multilingual context. They found that user-generated tags were in general of good quality, 30% of tag applications matched with descriptors found in a multilingual thesaurus, which had also been used to index these learning resources. The authors argue that these tags, called "Thesaurus tags" provide a bridge between tags and multilingual Thesaurus descriptors creating relationships between descriptors and tags. This allows linking to related Thesaurus descriptors in multiple languages and further supports the retrieval of resources in a multilingual context. Moreover, "Thesaurus tags" make it possible to add properties to tags (e.g. relation to a concept in multilingual Thesaurus, language). [BBM06] define a reversed method to this, a way to annotate learning objects with metadata, while providing enough semantics through an ontology like WordNet.

4. Exploiting context information for a better multilingual support

A good example of the use the knowledge about user's language context is the provision of a better-organised search result list: first a ranked list in the preferred language, then a ranked list in a second language, and so on. Such interface choices are currently made by Google for general search results and by LeMill (lemill.net) for learning resources. A related exploitation of the user's language context is to organise tag clouds by language or country as in LRE (lreforschools.eun.iorg), rather than to overwhelm users with tags in all languages.

These strict separations are especially suited for users with a strong preference for one language, e.g. the only language spoken, or if user has a preference for uni-lingual content. In [VK9b], for example, it was found that 17% of users had saved only content in their native language in their Favourites. In [VO09], it was shown that exceptions can become interesting for *travel-well tags*, which are terms with the same or similar spelling in most languages (e.g. technical terms like "mathematics", place and person names). These become an interesting option particularly for a less used languages or if the user is unknown. Identification of travel-well tags may be done by using a dictionary such as a multi-lingual thesaurus. However, they are also a good example of the multifaceted role of tags: a tag can be classified as travel-well based on the context and tagging metadata. I.e., if users from at least two different languages have assigned this tag, or if the tag has been assigned to learning resources that are themselves in more than one language. Travel-well tags have a counterpart in resources: travel-well resources are those that have been bookmarked by people from different language, but also country contexts, indicating that the resource can be useful regardless of its context.

Information on a user's language or her current input's language (where the latter may, in unclear cases, be inferred from the former) may also be used to give query recommendations. For example, Blanco and Lioma [BL09] found that Latinized versions of search terms often gave worse results than the correct, language-dependent spellings – encouraging users to use their own language rather than English may therefore help them get better search results.

Knowledge on users language contexts can be leveraged in recommendations on content or input in direct ways as shown above, by recommending content or tags in a preferred language, or in indirect ways, for example by recommending the bookmark list of other users with a similar "language preference profile" (including the degree of tolerance for mixed-language resources, results, etc.). Finally, repositories could specifically encourage users who are competent in "smaller" languages also to *author* content in their language. This could help counter the manifold and mutually reinforcing mechanisms on the Web that discourage non-English languages [BK09].

5. Outlook

In this paper we have studied the importance of "context" in the field of Technology Enhanced Learning (TEL), and discussed how measuring context can support multilingual and cross-lingual use of the tools and content that are offered in the cross-section of digital learning resource repositories, digital libraries and social tagging systems. A myriad of research challenges remain for designing adequate system responses and system outputs in the different *micro-contexts* that are enumerated in this paper.

References

[AYGS08] Au Yeung, C.; Gibbins, N.; Shadbolt, N. A study of user profile generation from folksonomies. In Social Web and Knowledge Management, Social Web 2008 Workshop, 2008.

[BBM06] Bateman S.; Brooks, C.; McCalla, G. Collaborative tagging approaches for ontological metadata in adaptive e-learning systems. In 4th International Workshop on Applications of Semantic Web Technologies for E-Learning (SW-EL 05), pages 3–12, 2006.

[Ber07] Berendt. B. Context, (e)learning, and knowledge discovery for web user modelling: Common research themes and challenges. In Proceedings of the Workshop on Data Mining for User Model ling at UM 2007, 2007.

[BH91] Brockett, R.G; Hiemstra. R. Self-Direction in Adult Learning: Perspectives on Theory, Research, and Practice. Routledge Series on Theory and Practice of Adult Education in North America. Routledge, Chapman and Hall, Inc., 29 West 35th Street, New York, NY 10001.1991.

[BK09] Berendt, B.; Kralisch, A. A user-centric approach to identifying best deployment strategies for language tools: The impact of content and access language on web user behaviour and attitudes. Journal of Information Retrieval, 12(3):380–399, 2009.

[BL09] Bianco, R.; Lioma. C. Mixed monolingual homepage finding in 34 languages: the role of language script and search domain. Journal of Information Retrieval, 12(3):324–351, 2009.

[BM06] Brooks C; McCalla, G. Towards flexible learning object metadata. International Journal of Continuing Engineering Education and Life-Long Learning, 16(1/2):50 – 63, 2006.

[BS00] Berendt, B; Spiliopoulou, M. Analysis of navigation behaviour in web sites integrating multiple information systems. The VLDB Journal, 9(1):56–75, 2000.

[CHM02] Colley, H.; Hodkinson, P.;Malcom, J. Non-formal learning: mapping the conceptual terrain. a consultation report. 2002.

[CLWB01] Claypool, M.; Le, P.; Wased, M; Brown, D. Implicit interest indicators. In Proceedings of the 6th international conference on Intel ligent user interfaces, pages 33–40. ACM, 2001.

[CSB+07] Cattuto, C; Schmitz, C; Baldassarri, A; Servedio, V. D. P.; Loreto, V.; Hotho, A., Grahl, M.; Stumme, G. Network properties of folksonomies. AI Commun.,20(4):245–262, 2007.

[Dey01] Dey. A. K. Understanding and using context. Personal and Ubiquitous Computing, 5(1):4–7, 2001.

[Eng87] Engeström, Y. Learning by expanding: An activity-theoretical approach to developmental research. Orienta-Konsultit Oy, 1987. http://www.hcirn.com/ref/refe/engy87.php.

[Gra05] Graham, C., R. Blended learning systems: Definition, current trends, and future directions. In C Graham and C Bonk, editors, Handbook of blended learning: Global Perspectives, local designs, pages 3–21. Pfeiffer Publishing, 2005.

[HHN06] Harley, D.; Henke, S.; Nasatir, D. Use and Users of Digital Resources: A Focus on Undergraduate Education in the Humanities and Social Sciences. Digital Resource Study. 2006.

[JHW07] Jung, S.; Herlocker, J.L; Webster, J. Click data as implicit relevance feedback in web search. Inf. Process. Manage., 43(3):791–807, 2007.

[KPW+08] Khoo, M; Pagano, J; Washington, A.L.; Recker, M.; Palmer, B; Donahue, R.A. Using web metrics to analyze digital libraries. In Proceedings of the 8th ACM/IEEE-CS joint conference on Digital libraries, pages 375–384. ACM, 2008.

[Lon03] Longworth, N. Lifelong learning in action - Transforming education in the 21st century. Kogan Page, 2003.

[LS00] Lieberman, H.; Selker, T. Out of context: computer systems that adapt to, and learn from, context. IBM Syst. J., 39(3-4):617–632, 2000.

[MC07] Michlmayr, E; Cayzer, S. Learning user profiles from tagging data and leveraging them for personal(ized) information access. In the Workshop on Tagging and Metadata for Social Information Organization,

[ML08] Margaryan, A.; Littlejohn, A. Repositories and communities at cross-purposes: issues in sharing and reuse of digital learning resources. Journal of Computer Assisted Learning, 24(4):333–347, 2008.

[Moo03] Moore, M. Handbook of distance education. L. Erlbaum Associates, 2003.

[NM07] Noll, M; Meinel, M. Web search personalization via social bookmarking and tagging. In Proc. of ISWC 2007, 2007. http://iswc2007.semanticweb.org/main/default.asp.

[NWD06] Najjar, J; Wolpers, M; Duval, E. Towards effective usage-based learning applications: Track and learn from user experience(s). In Proceedings of the Sixth IEEE International Conference on Advanced Learning Technologies, pages 1022–1024. IEEE Computer Society, 2006.

[OBHG03] Oberle, D.; Berendt, B.; Hotho, A.; Gonzalez, J. Conceptual user tracking. In E Menasalvas Ruiz, J Segovia, and P Szczepaniak, editors, of Lecture Notes in Computer Science. Springer, 2003., volume 2663 of AWIC, page 155164, 2003.

[Och08] Ochoa, X. Learnometrics: Metrics for Learning Objects. PhD thesis, K.U.Leuven, Belgium, 2008.

[PNJK08] Petrides, L; Nguyen, L.; Jimes, C.; Karaglani, A. Open educational resources: inquiring into author use and reuse. Int. J. Technol. Enhanc. Learn., 1(1/2):98–117, 2008.

[RV07] Romero, C.; Ventura, S. Educational data mining: A survey from 1995 to 2005. Expert Systems with Applications, 33(1):135–146, Jul 2007.

[Sch02] Schmidt, A; Ubiquitous Computing - Computing in Context. PhD thesis, Computing Department, Lancaster University, U.K., November 2002.

[SNCNR09] Santos-Neto, E.; Condon, D.; Nazareno, A., Ripeanu, M. Individual and social behavior in tagging systems. In 20th ACM Conference on Hypertext and Hypermedia, 2009.

[SNRI08] Santos-Neto, E.; Ripeanu, M.; Iamnitchi, A. Content reuse and interest sharing in tagging communities. In Technical Notes of the AAAI 2008 Spring Symposia - Social Information Processing, 2008. http://arxiv.org/abs/0711.4142.

[VK9a] Vuorikari, R.; Koper, R. Evidence of cross-boundary use and reuse of digital educational resources. submitted, 2009a.

[VK9b] Vuorikari, R.; Koper, R. Ecology of social search for learning resources. Campus-Wide Information Systems, 26(4), 2009b. http://dspace.ou.nl/handle/1820/1799.

[VO09] Vuorikari, R., & Ochoa, X. (2009). Exploratory Analysis of the Main Characteristics of Tags and Tagging of Educational Resources in a Multi-lingual Context. Journal of Digital Information, 10(2).

[VPK09] Vuorikari, R.; Poldoja, H.; Koper, R. Comparison of educational tagging systems any chances of interplay? IJTEL, 2009. http://dspace.ou.nl/handle/1820/1798.

[VSPK09] Vuorikari, R.; Sillaots, M.; Panzavolta, S.; Koper, R. Are tags from mars and descriptors from venus? a study on the ecology of educational resource metadata. In M Spaniol, editor, Advances in Web-Based Learning - ICWL 2009, volume 5686/2009 of Lecture Notes in Computer Science, page 400409. Springer-Verlag, 2009. http://dspace.ou.nl/handle/1820/1849.

[WK89] Wahlster, W; Kobsa, A. User models in dialog systems. In A. Kobsa and W. Wahlster, editors, User Models in Dialog Systems, pages 4–34. Springer, Berlin, Heidelberg, 1989.

[WMND06] Wolpers, M; Martin, G; Najjar, J; Duval, E. Attention metadata in knowledge and learning management. In Proc. IKNOW 06, 2006.

[WNVD07] Wolpers, M; Martin, G; Najjar, J; Verbert, K.; Duval, E. Tracking actual usage: the attention metadata approach. Educational Technology and Society Journal, page 106, 2007.