
ENHANCING LEARNING WITH TECHNOLOGY

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Abstract: *We are living in a technology-enhanced world. Also learning is affected by recent, upcoming, and foreseen technological changes. This paper gives a bird's eye view to technological trends and reflects how learning can benefit from them.*

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1. INTRODUCTION

Technology is deeply embedded in our daily life as also in our learning support. Discussions about the efficient and effective use of technology and the development of new approaches for media in education are topics of general awareness and societal relevance. Nevertheless the efficiency and effectiveness of the use of technology to enhance learning experiences compared to other factors in the educational setting is little [15]. Even more and as a consequence of the lack of research on the effectiveness and efficiency of technology usage for enhancing learning and teaching often technology is banned from today's classrooms. Additionally this also leads to the consequence that initiatives to develop new technologies rarely are driven from the actual needs in the educational sector but in most cases technologies are adapted to also fit the educational needs.

This paper introduces several upcoming and recent technology developments and positions them according to four main dimensions in which technology can extend and enhance existing and established educational settings and tools. In this sense the underlying dimensions are also key components of enhancing educational offers and teaching and learning.

The dimensions are related to inherent characteristics of recent ICT:

- **Storage:** ICT technologies offer new possibilities considering the storage of information. Storage enables the instant availability of huge masses of information and makes the masses of information indexable, quickly accessible, and mobile. Combining storage with new methods of data logging and user tracking enables basically complete storage of a person's progress on selected dimensions and data points in digital form. On the one hand this leads to simple but very effective solutions for cloud-based information sharing in schools as also to inquiry-based learning support and a linkage between school curriculum and learning content in and out of school.

- **Connectivity:** From local solutions the networking capabilities of ICT enable several new extensions of classical learning settings, ranging from social media and massive open online courses (MOOC) to massive multi-player online role playing games (MMORPG) to mobile solutions in which the local context plays an important role like in location based services. The connectivity of mobile devices changed the communication behaviour of new generations, with positive and negative consequences.
- **Computational power:** ICT has the capability for fast integration and computation of complex models and to "crunch numbers" and visualize big data. Nowadays especially the combination of storage, connectivity, and computational power enables distributed, service-oriented systems that combine a variety of individual services with mobile user interfaces and situated access to deliver complex, high-level services and information in close to real-time. Learning processes can benefit from higher quality simulation processes, learning analytics, and access to real-time information and context services.
- **Context-awareness:** New computational systems are increasingly combined with sensor-based user interfaces. Sensor information is used to enable new user experiences and in-situ interaction with digital information and is provided in context-aware applications. Context-awareness reduces the distance between the current contexts of use of a technology and also enables the support of seamless learning [52] across different learning contexts. In that sense the classroom of tomorrow is distributed and open but linking to a core situation of learn-full interaction.

In the following we will introduce technology that can enhance and have partly shown to do so and discuss them in relation to these dimensions.

2. A TECHNOLOGY ENHANCED WORLD FOR LEARNING

Human enhancement refers to any attempt to temporarily or permanently overcome the current limitations of the human body through natural or artificial means [50].

Technology enhanced learning in this sense refers to the enhancement of learning support via information and communication technology (ICT). Enhancing the human capabilities to work with information is a key concept that is already embodied in very old tools as paper and pencil. Paper and pencil enable humans to make information persistent, to illustrate, to annotate, to distribute and much more.

As such new media and technologies can enable humans to solve more complex tasks or even develop new skills with digital tools. In the following sections we would like to classify different technology trends currently relevant for Technology Enhanced Learning (TEL).

High-level technology trends relevant for TEL

In general there are several high level technologies that can be identified as relevant for learning. In its yearly reports the Horizon Project analyses and describes main technology trends and their impact on teaching, learning, research, or creative expression. In 2009 the Horizon Report explains several technologies, which will “significantly impact the choice of learning focused organizations within the next five years” [19].

The six topics highlighted in the 2009 report were Mobiles, Cloud Computing, Geo-Everything, the Personal Web, Semantic-Aware Applications, and Smart Objects.

Mobiles as learning technology have surfaced in several of the recent reports and have dramatically evolved in the last ten years. Nowadays mobile devices can be context-aware of their environment, or already have built-in sensors to read Radio Frequency tags. Flat rates for cheap data access have been established around the world and these devices can be equipped with special software and applications. As an example the Apple Application store holds around 600.000 specialised applications that can be installed on a mobile phone or a tablet computer. Mobile devices became flexible multipurpose tools for accessing information and services linked to the real world.

Cloud computing relieves the end user of thinking about storage and access to data and services. Commercial services today allow you to have personal information distributed, updated, and accessible from a variety of devices. Social web services have driven this for all kinds of media like photos, videos, calendars, documents, or notes. Cloud computing gives you access to all your personal information just with a network connection and synchronised over a variety of mobile and computer terminals.

Geo-Everything allows everyday users to save location information with almost every kind of media they produce. Applications today already automatically add data about the location where you have taken photos, videos, or audio recordings. First applications in education have explored this in the area of educational field trips but as new developments on mobile augmented reality demonstrate there is still a lot to come from geo-tagged media. In general all kinds of context metadata

will enable new ways of filtering and interacting with content in context.

The personal web is also a topic that reoccurred in the last years. Before cloud computing and user-friendly mobile devices it was still very difficult for the average computer user to build personal websites; however, with media today this is easy. Everyday users can create personal web blogs, photo galleries, video channels, or audio stations, just by adding files from a local recording device in a short time. The creation of media for the personal web will be pushed via mobile content creation and this will make mobiles more interactive and personal tools.

Smart-Objects are connected to the topic of Internet of Things. Today we are rapidly moving towards an Internet of Things where not only digital information is stored on the web, but also physical world objects enriched with sensors become aware of their environment. Connecting information and learning services to artefacts will be a next logical step when implementing ubiquitous learning support. Designers will embed interaction facilities into everyday objects, which will be intuitive to use while still augmented.

Most of these technologies interconnect the real world and the information world. We consider this relation as a core for contextualised learning support [13].

Over the years the reports also have identified key challenges to the technology trends identified. In 2011 key-trends and challenges have been identified as:

- Abundance of resources and relationships is more and more challenging for educators.
- People expect to be able to work, learn, and study whenever and wherever they want.
- A world of work, which is increasingly collaborative, also challenges to reflect on the structure of student projects.
- Digital media literacy continues its rise in importance as a key skill in every discipline and profession.
- Economic pressure challenges traditional models of education and educational institutions.

In general the usage of mobile technology has an impact and plays an important role in many of these developments.

On the one hand, mobile and embedded technology enable ubiquitous access to information and integrate information display and access in traditionally static or manually controlled displays and visualisation tools as blackboards. This does not only change the availability of computational power in the classroom and the availability of content, but also has high implications on the design and the structuring of physical spaces as classrooms today. Furthermore, through the integration of new forms of human computer interaction this also has implications for the social relationships and the group interactions in the classrooms. In that sense, the ubiquitous and cloud-based access to information is linked to the topic of seamless integration of learning support and bridging the

gaps between different learning contexts. Furthermore mobile technology enables the linking of informal learning and non-classroom activities with traditional learning.

On the other hand, the use of mobile devices and embedded technology also support the integration and use of these technologies in classically not “computerised” contexts of work, leisure, and learning. In that sense the linking between classical physical environments and digital media is a key research challenge, which is linked to technology trends as augmented reality, geo-everything, data-mashups, or smart objects. In general these technologies and trends aim at the support of deepening and broadening learning experiences in context more than bridging between contexts.

Additionally mobile technologies open up new opportunities for linking and bridging between contexts. This is linked to the seamless support of learning activities distributed across time, space, and social contexts.

3. TRENDS IN MOBILE AND CONTEXTUAL TECHNOLOGIES RELEVANT FOR TEL

In a recent report of the STELLAR Network of excellence in TEL, the following important technology trends in contextualised and ubiquitous learning have been identified.

Location-based and contextual learning

In the first Alpine Rendezvous supported by STELLAR a workshop on Location-based and contextual learning has been organized and the report that consolidates the main research trends and issues has been published and widely cited [6]. The workshop aimed at sharing good practice of research innovations and case studies, engaging in debate and discussion of critical issues surrounding contextual and location-based mobile learning both currently and in the future and to conduct future-scanning activities in contextual and location-based learning.

“The workshop explored recent innovations into location-based, or geospatially-informed, contextual mobile learning, and issues arising from them. Location-based technologies offer opportunities for new forms of learning that engage more deeply with physical surroundings and support continuity of understanding across settings; they also pose technical difficulties of modelling and maintaining continuity of context, and ethical challenges including the right to privacy of location and escape from continual monitoring.”

Smartphones as generic mobile learning tools

Mobiles as learning technology have surfaced in several of the recent reports and have dramatically evolved in the last ten years. Nowadays, mobile devices can be context-aware of their environment, and already have built-in sensors ranging from location sensors to detailed 3D movement gyroscopes. Flat rates for cheap data access have been established around the world and these devices

can be equipped with special software and applications. In that sense, smartphones become more and more universal tools for dedicated purposes and apps even become available cross platform so that the seamless use of services in combination with smartphones becomes more or less a commodity.

For mobile access to information all major Learning Management Systems (LMS), both open source and commercial, offer mobile solutions nowadays. While the functionality of these mobile LMS support varies between support simple updating and news functionality to full fledged access to an LMS.

The multipurpose usage of mobile devices can be structured best according to the educational functions these tools support:

- Mobile content and LMS access,
- Personal notification systems,
- Response systems either in Classroom Response Systems or in distributed collaboration systems,
- Data collection tools for documentation of learning experiences.

Mobile Serious Games

Within the past five years, the number of Mobile Learning Games has snowballed. For commercial and for scientific use they have been developed for various target groups and learning contexts [24] such as role-based history learning [1], interactively discovering the principles of digital economy [27] or geometry [53].

Concurrent to the quickly developing field of digital games, there have been efforts to find a common structure and language for this vast field to better understand the complex issue [5][22][7]. The highly complex technologies and the many different gaming opportunities available make it increasingly difficult for educational practitioners to decide which game to choose for learning.

Games are mostly categorized according to game genres i.e. adventure games, role-playing games, strategy games, or simulations [34]. In the context of current game research activities this categorization has proved to be of little use [14][8]. Especially in the context of educational games the traditional categorisation of games according to genres is not stable and rather difficult to apply. This is due to the vital need for tailoring learning offers (i.e. educational games) according to the learners needs and according to the learning target instead of fixed genre features.

Different educational effects of mobile learning games have been researched mostly in the areas of cognitive and affective learning outcomes.

Mobile Augmented Reality

Until recently, augmented reality (AR) applications were mostly available for powerful workstations and high power personal computers. The introduction of augmented reality applications to smartphones enabled

new and mobile AR experiences for everyday users. Because of the increasing pervasion of smartphones, AR is set to become a ubiquitous commodity for leisure and mobile learning. With this ubiquitous availability, mobile AR allows to devise and design innovative learning scenarios in real world settings. This carries much promise for enhanced learning experiences in situated learning. A recent overview is given in [43].

Like context-aware systems, augmented reality applications make it possible to filter information and present information overlays relative to the user's current context [54][55]. Information in context can be filtered according to location, movement path, facing direction, object in focus, time period or according to meta-information such as the learner's personal interests or profile.

In addition to this conceptual model of AR applications, an engineering perspective is required to understand the technical components and their role in mobile AR systems for learning. In their description of the history of mobile AR, [48] has identified the following technical components of mobile AR systems as being important:

- Flexible Display Systems: this includes head mounted display systems, camera phones, and hand-held projectors. Display technologies become increasingly more flexible and cheaper to produce. These technologies enable the augmentation of everyday vision of mobile users.
- Sensor systems in mobile devices like gyroscopes, GPS, electronic compass, cameras, microphone, as well as indoor location tracking systems.
- Wireless networking protocols and standards supporting indoor and outdoor augmentation settings. These also enable multi-user real time interaction in the augmented reality.
- Mobile Phones with computational power to do real time visualization of 3D objects and overlays on a standalone device.
- Tagging and tracking technologies with six degrees of freedom, multi-marker tracking, and hybrid tracking systems. This is also related to one of the most researched areas in AR, the registration problem [4]. It describes the problem of linking the real world perception of a mobile AR user and the presentation of the augmentation layer. Thus, the registration problem is closely linked to what we have been referring to as synchronisation.
- Linking of location-based AR information in storytelling and gaming approaches. In most cases AR is used as an ad-hoc technology that extends certain environments, new approaches should also combine the use of AR with instructional designs and user assignments. Storytelling and gaming approaches are currently the most prominent approaches.
- Flexible layer-based AR browsers with integration of social media. Basically, AR systems must also build on existing information channels and can present existing information to users in a new kind of user interface. Therefore, implementations of mobile AR

for learning must enable open interfaces to existing content and services.

Mobile AR can be applied in various educational domains. It can help learners to gain a deeper understanding, experience embedded learning content in real world overlays, or explore content driven by their current situation or environmental context. Most prominent examples support exploration of the physical environment with different topics of interest, e.g. history, arts, technology, biology, astronomy and others, or by enriching artefacts in the physical environment with AR techniques. In general, AR technically is divided in marker-less and marker-based AR to register digital content for real world orientation and placement. A number of educational patterns are related to the interaction patterns discussed earlier. The patterns described below connect an educational objective to the usage of certain dimensions of context [42] in synchronising the augmented reality layer with real world learning situations.

Cloud computing for seamless learning support

Cloud computing relieves the end user of thinking about storage and access to data and services. [37] discuss the following advantages to use cloud computing for mobile learning: costs, flexibility and accessibility. Commercial services today allow one to have personal information distributed, updated, and accessible from a variety of devices. Social web services have driven this distribution and storage of personal data in the cloud for all kinds of media like photos, videos, calendars, documents, or notes.

This trend is clearly linked to the seamless and ubiquitous access to information. Its usage and scenarios in educational scenarios are limited till now. The cloud offers a lot of potential to ensure access to important resources and information like learner profile data (e.g. prior knowledge, preferences), learning resources but also process related information like learning paths or current level for a specific learning goal. In combination with context filters and mobile applications the cloud can become the basis for a mobile personal learning environment (PLE). PLEs are socio-technical frameworks in which learners combine digital resources, information and contacts to monitor, reflect and document learning products and learning processes that can be shared again on the basis of standards.

The cloud unlocks a new potential for the development of seamless learning support that overcomes the existing problems of time and location and allows for a truly ubiquitous learning experience.

Sensor Technology for usage and activity tracking

Tracking information about learners and their learning progress is at the core of computer based educational systems. Especially adaptive educational systems used assessment and user tracking for personalisation of interaction with the learner. Adaptive feedback, navigation support, and tutoring of computer-based

systems are in most cases based on the assessment of performance of learners or on user preferences.

Different forms of data acquisition range from using learner's interaction history, analysis and data mining of footprints, to highly sophisticated assessment processes integrating a variety of methods. In general, the more data is available about learner activities, the more accurate adaptive systems can adapt to learners and support personalised learning.

Going one step further, users of mobile sensor technologies start to collect private datasets for reflection and monitoring of daily activities as in the Quantified Self movement [46]. While partly the collected data is based on individual protocols, logbooks, and notes also a whole set of best practices and technical tools, sensor gadgets, and mobile apps are described to track user behaviour. The application fields of sensor tracked data range from energy, fitness, mood, productivity, or relationship tracking, as also tracking learning progress [39].

While the idea of using sensors has been used already quite some time in physical education and advanced sports training, life logging and sensor tracking applications nowadays are used in a wide range of application fields such as health, nutrition, life-style, fitness, sleep, or productivity.

New kinds of sensor devices like the Fitbit support users monitoring their health, weight, sleep behaviour and other parts of their daily living. Technically it is possible to track activities, geo-spatial movements, physical activities, social relationships, as also detailed biophysiological data about learners and their daily practices. Nevertheless there is a core question about the underlying mechanisms and how these new forms of user tracking and the feedback based on this information can be best integrated in instructional designs and educational systems.

Recently [12] has described the power of feedback loops and real-time sensor feedback for human behaviour change ranging from power consumption, medication, health monitoring, and other fields. As a core principle even redundant information visualised in feedback-loops in the right context is an efficient mean in self-regulation to monitor, analyse, and regulate ones personal learning process.

Furthermore sensors play a crucial role in contextualisation. Sensors allow users to get information about their environment, enable new forms of user interaction, and connect the real world with information objects.

Ambient and Situated Displays

To approach the abstract concept of ambient displays it is beneficial to start with a definition of its words. The adjective ambient is defined as "relating to the immediate surroundings of something" or "relating to or denoting advertising that makes use of sites or objects other than

the established media" [33], while the noun is defined as "a collection of objects arranged for public viewing", but also as "an electronic device for the visual presentation of data or images" [33]. Following these definitions the compound term ambient displays characterises appliances present in the close proximity of mainly visually solicited receivers. The technical term this review is referring to goes beyond this mere linguistic definition, describing a renunciation of human-computer interaction (HCI) paradigms where information is delivered constantly demanding the focus of attention. Looking beyond this unilateral communication channel Wisneski et al. introduced ambient displays as "new approach to interfacing people with online digital information" [51]. Inspired by Weiser's vision of ubiquitous computing [49] the "information is moved off the screen into the physical environment, manifesting itself as subtle changes in form, movement, sound, colour, smell, temperature, or light" [51]. Instead of demanding attention the approach exploits the human peripheral perception capabilities.

Following Wisneski's view [51] on ambient displays, who basically defines ambient displays as embedded in the environment close to the user and presenting information related to the user's current context, awareness can be deduced as a main instructional characteristic of ambient displays. To grasp the application possibilities of ambient displays in learning contexts this concept needs to be further exploited, e.g. by accomplishing this perspective with the concept of situational awareness. Endsley [10] defines situational awareness as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future".

Following this definition the author presents three levels of situational awareness that can be used for classification, namely perception, comprehension, and projection. Perception is related to situational cues and important or needed information, comprehension relates to how people integrate combined pieces of information and evaluate their relevance, and finally projection relates to how people are able to forecast future events and situations as well as their dynamics. Especially on the higher levels of situational awareness the type and characteristic of feedback given by the ambient displays plays an essential role for their effectiveness, impact, and behavioural change capabilities and thus is another important instructional characteristic that can be deduced. In that sense also the concept of providing (instructional) feedback needs to be incorporated, whereas [31] provided an extensive research review.

As mentioned the actual information presented through the display might be delivered addressing the receiver's vision, hearing, haptic, olfaction, or taste utilising ambient information systems. Based on a comparison and discussion of existing ambient information systems in [36] respective systems can be classified. The four design dimensions information capacity, notification level, representational fidelity, and aesthetic emphasis are thus used within the classification framework to describe the

reviewed ambient display prototypes. According to the authors information capacity is determined by the amount of information represented by the system, notification level is the degree of user interruption, representational fidelity describes how the data is encoded, and the last dimension reflects the emphasis put on aesthetics [36].

Analysing and classifying work in the research field of ambient displays with a focus on their use for learning support highlights ambient display characteristics. Across the reviewed articles the individual characterisations of ambient displays are diverse and multifaceted, still mostly building upon the definition by [51]. Following this definition under consideration of interactional, instructional, and informational aspects several characteristics can be derived.

Approaching interactional aspects, ambient displays are characterised as informative appliances that are embedded into the physical environment [2]. Thereby the embedding is supported and fostered by an unobtrusive and peripheral design [41]. In addition, ambient displays are characterised as addressing various forms of sensitive perception [26].

Regarding the instructional aspects of ambient displays the main characteristic described is the utilisation of subtle communication methods mainly out of the focus of attention [45]. This general characteristic is complemented by several requirements, such as to be glanceable and pre-attentively comprehensible [26] as well as not distracting nor demanding attention [16]. Another complement is the instructional ability to move from the periphery to the focus of attention and back [11].

Conclusively two characteristics approaching the informational aspect can be derived from the reviewed articles. Ambient displays distribute non-critical information [3], although the information is often contextualised and enriches the environment [29], and they support and establish informational awareness [38]. In addition to the presented core characteristics some authors also lay a particular emphasis on aesthetical features and decorativeness. These characteristics complement several interactional and instructional characteristics mentioned above.

Tangible Objects for Learning

In 2009 smart objects have been named in the Horizon report as one of the relevant technology trends with a time-to-adoption between four to five years [19][20][21]. In principle the report defines smart objects as “objects that know about themselves and link the real world with digital information”. Smart objects in that sense use embedded technology to track state changes in the environment and their context. Relevant technologies are QR codes and barcodes, RFID and NFC technologies, all other kind of embedded sensor technologies that can track changes of objects state as accelerometer, magnetometer, gyroscope, and others. The capacity to integrate smaller and more sophisticated digital technology into physical objects has created a new generation of materials (e.g.

SnapToTrace electronic textile from [44] and the Embedded soft Material Displays) in order to improve and augment tangibles as stated by [25].

In the research on tangible interfaces different classification systems have been proposed since [18] published and defined the term “tangible bits” as “...an attempt to bridge the gap between cyberspace and the physical environment by making digital information (bits) tangible”. Based on how tight the mapping between physical representations and digital information is implemented, [35] classified tangible interfaces into indices, icons, and symbols. [17] went further on the nature of this mapping and categorized tangible technologies into containers, tokens and tools. In his distinction, containers are generic objects used to move information between different devices and platforms, tokens are handlers for accessing stored information, tools are used to manipulate digital information with which they are associated. Furthermore, Holmquist’s classification is based on the degree of how well the physical object reflects or enacts the digital information.

Similarly [23] considered a weak and a strong degree of coherence between the physical and the digital object as relevant. As an example of a high level of coherence, a digital pen could be considered as an object with coherent form, function, and manipulative characteristics in the digital and the physical world. The weakest level of coherence could be represented by a mouse device, as the physical object doesn’t enact the actions that can be performed making use of it.

[28] suggests two kinds of activities for using tangibles in learning: expressive and exploratory. On one hand, expressive tangibles would be the ones that enable learners to create their own external representations. On the other hand, exploratory tangibles support learners to focus on the way in which the system works, rather than on their own representations.

There is the underlying assumption that using tangibles is beneficial but some authors like [47] and [9] have claimed that effectiveness in manipulatives in learning is not consistent. These authors state that the process of associating an abstract idea (e.g. mathematical expression) or a symbolic function to an object is not developed with the same effectiveness depending on the learner.

However, the research in this field has helped to articulate various mechanisms by which tangibles have benefits on learning. Montessori thought “learning is a physical act” and demonstrated that young children are intensely attracted to sensory development apparatus [30]. This phenomenon has been widely studied as embodied cognition based on the idea that the motor system influences our cognition, just as the mind influences bodily actions. Montessori believed that physical engagement can support learning by providing concrete anchors for theoretical concepts. More recent research on tangibles for learning by [32] concluded that physical activity itself helps to build representational mappings

that serve to underpin later more symbolically mediated activity after practise and the resulting 'explicitation' of sensorimotor representations.

Moreover, [32] enumerated some benefits to take into account: tangibles bring physical activity and active manipulation to the forefront of learning, i.e. reduces learner's cognitive load for performing non-content related tasks in order to enable learners to allocate cognitive resources and understanding the educational content of the learning task. [40] carried out a study in which he determined that learning with tangibles is not only active learning, it is also important to build in activities that support children in reflecting. This study examined the role of interface manipulation style on reflective cognition and concept learning.

4. CONCLUSIONS AND SUMMARY

In this paper we have described several high-level trends and developments in the technology sector. Enhancements of human learning support can on the one hand be achieved if a more efficient access to information and services embedded in the actual problem solving process and linked to current user situation can be achieved. Several of the introduced technologies can be used to achieve this.

In general most technologies relevant for educational settings extend current limitations of access to information and enable ubiquitous and seamless information access. One of the most important challenges nowadays is to make these technologies disappear in several ways. On the one hand these technologies must become easy to use and therefore not stand between the interacting stakeholders but link their main activities in a way that uses storage, computation, connectivity, and contextualisation. On the other hand educators must form a future vision of what makes learning more efficient and effective and then challenge engineers for building the technologies needed. As more society understands the importance of knowledge and competence in a knowledge society this seems to become a realistic approach. In that sense the current introduction of technologies and technology in innovation should also seek a more disruptive innovation approach.

In summary current technology developments enable more integrated learning support of sensing the current learner's context and giving real-time feedback on the learner's behaviour. This can lead to more efficient and effective learning when the relevant data about a user's behaviour (sensing) is brought together in a meaningful way (aggregation) combined and implemented in instructional strategies (control) and indicated in a intuitive, meaningful, and stimulating way (indication).

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