On the Implications of Human-Paper Interaction for Software Requirements Engineering Education

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***Abstract*—It is broadly accepted that requirements engineering is one of the most important phases of a software project, and requires tools to be effective. For a variety of reasons, paper as a tool has lasted for millennia and remains ubiquitous. This paper makes a case for a contextual, conscientious, and evidence-based use of paper in a competency-oriented approach to software requirements engineering education (REE). It argues that the prophecies for the obsolescence of paper are premature, there are unique benefits in the use of paper, and the decision to use paper should be based on [0, 1] rather than {0, 1}. In this regard, a need-centered conceptual model for human-paper interaction is proposed. The characteristics of paper that make it historically unique are reported and the affordances of paper relevant to REE are discussed. The REE-related activities that benefit from viewing paper as a boundary object and using different types of paper are highlighted and illustrated by means of examples. In advocating polyliteracy, the potential for a convergence of paper and digital media towards a harmonic coexistence is underscored.**

Keywords-active learning; affordance; conceptual modeling; design thinking; human-centered agile methodology; software psychology

I. INTRODUCTION

The significance of *software requirements engineering* (RE) [1, 2] is underscored by the fact that it is a phase in which the stakeholders exercise considerable control over the success of the software project, and the decisions made during this phase usually have a major, often irreversible, impact on the subsequent phases. In the past 50 years or so, RE has evolved from an almost exclusively technically-oriented endeavor addressing mathematical problems to a contextually-, anthropologically-, and socially-sensitive discipline tackling ill-structured problems, such as "wicked problems". This change invariably impacts how *software requirements engineering education* (REE) should be perceived, planned, and pursued [3, 4], what the expected role of a software requirements engineer needs to be [2], and what the desirable competencies of a software requirements engineer are to be [5, 6].

As with many other software processes, a proper enactment of a RE process usually and inevitably involves using tools. The selection, adoption, and use of RE tools should be based on evidence rather than exuberance, understanding that professional tools do not automatically or necessarily meet the criteria of educational tools, determination that return on investment (ROI) >> 0, and consideration of the long-term consequences of a selection. One such candidate tool is paper. In that regard, the purpose of this paper is to investigate the extent to which paper can be useful as a tool for certain common activities in REE [7], the properties of paper that enable them, and the underlying reasons for this phenomenon.

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The rest of the paper is organized as follows. In Section II, necessary background is provided and related work is discussed. A theoretical and practical understanding of the use of paper in REE from the perspective of human interaction is explored at some depth in Section III. In Section IV, potential directions for future research are outlined. Finally, in Section V, concluding remarks and recommendations are given.

II. BACKGROUND AND RELATED WORK

A. Characteristics of Paper relevant to REE

There are several distinctive, organic, and anthropomorphic characteristics of paper, such as the following:

- **Breathability.** It can retain (pencil) lead or absorb (pen) ink for a long period [8].
- **Emotivity.** It can give rise to different emotions among its users [9]. For example, a paper book can be perceived as a "beautiful object" (https://beautifulbooks.info/), and can add to the décor of a domicile. Indeed, people can create an emotional attachment with the paper books they have owned or read. The emotion can manifest in one or more different ways as, for example, identified by the *Plutchik's Wheel of Emotions*. For example, looking forward to and acquiring a paper book can make people happy, and losing it can make them sad.
- **Identity.** It can have a unique *persona* depending on the properties attributed to it during production (such as caliper, grammage, permeability, size, texture, and so on), making it recognizable even to those with visual impairment. For example, a paper book could be spotted from a distance, say, when it is on a shelf or table.
- **Resiliency.** It can be used even if it somewhat loses its original shape, say, is slightly crumpled, smudged, or torn. In other words, its utility and usability vary on a *continuous* set rather than on a discrete (binary) set.
- **Tangibility.** It can be touched and felt, and has friction. This, apart from physiological and psychological implications, creates a sense of *ownership*, and with ownership come *responsibility* and repercussions. For

example, ruining or losing a sheet of paper has meaning (as, at the very least, there is no automatic backup copy). In other words, "you broke it, you own it".

- **Temporality.** It can give a sense of passage of time (say, through signs of aging, decay, and smell), similar to a living being. This can bring about affinity and nostalgia among its owners.
- **Versatility.** It is a *boundary object*, and as such can be cut, flipped, folded, orientated, spindled, or torn in a variety of ways and shapes to suit users' preferences. For example, multiple, small sheets of paper can be produced "on-the-fly" from a single, large sheet of paper, and, conversely, a single, large sheet of paper can be created by gluing or taping together multiple, small sheets of paper.

These characteristics are not only among the reasons for the persistence of paper over millennia, but also have implications towards REE (and beyond), as discussed later.

B. Paper and the History of Computing

The history of large-scale programming in the 1950s, and subsequently of software engineering in the 1960s and 1970s, is an indicator of how the paper types and the degree of paper uses in these disciplines evolved, namely from more in the product I/O and less during the process to more during the process and less in the product I/O, as illustrated in Fig. 1 using color for emphasis. This transition could be attributed to the advancement of technologies for and the reduction in the cost of necessary hardware and software for I/O, and the increased attention on the principles and practices involved in processing.

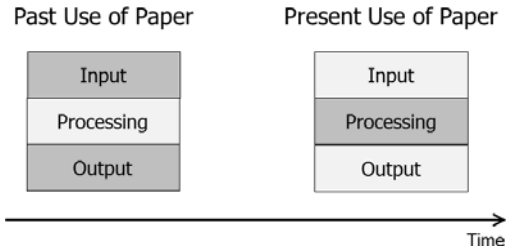

Figure 1. The uses over time of paper in computing.

The panorama of paper uses and paper types changed with the changes in the nature of computing, as some entered and the others exited. For example, the *punched card*, used for program input, is essentially obsolete because everything useful that was possible using it can be done otherwise, more effectively and efficiently. An almost similar argument could be made for *continuous paper* (such as the line printer paper), used for program output, as far as the consumption by public-at-large is concerned.

There have been calls since 2000s advocating the use of paper, albeit more so in human-computer interaction than in software engineering [10]. This situation, however, is changing as the two disciplines converge by necessity, such as seen by increasing human-centeredness of software development methodologies, in general, and agile methodologies, in particular [11]. For example, one of the values stated in the *Agile Manifesto*, namely "individuals and interactions over processes and tools", can be realized in practice if there is explicit attention on the *stakeholders needs* and there is inclusion of *lightweight tools*, such as paper. Indeed, this can be accomplished by integrating *design thinking* and *human factors design* in an agile methodology, such as *Scrum* [12]. For another example, the *Kanban Pizza Game* is played using pieces of paper representing the ingredients of a typical pizza [13]. However, there is much to be desired for making a case for paper in RE, in general, and REE, in particular, and that is one of the motivations of this paper.

C. Paper in Context from a Human Interaction Perspective

There have been a number of empirical studies over the years deliberating, evaluating, and reporting on relative merits of using paper and digital media for certain activities [8, 14]. (For the sake of this paper, *digital media* is some data presented using an application software, on a hardware device capable of digital computing, for the purpose of consumption by humans [8].) In that regard, it could be noted that paper and digital media appeal to different human senses [8, 15], reading on physical medium is different from that on digital medium [8, 16, 17, 18], and handwriting is different from typing [19].

An *affordance* is a property, or multiple properties, of an object that provides some indication to a user of how to interact with that object or with a feature of that object [15, 20]. Fig. 2 presents a Venn Diagram of two sets, one for the affordances of paper and the other for the affordances of digital media. In literature, the comparisons between paper and digital media are often restricted to comparison between C and B (= $(B - A) \cup C$), that is, anything that can be achieved with paper can also be achieved by digital media and digital media can achieve more, and do not consider $A - B$. C reflects early days of digital media when it tried to mimic and duplicate some of the affordances of paper [8].

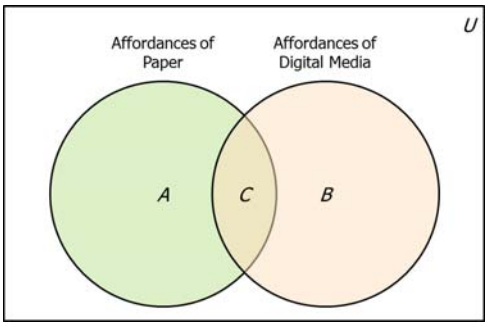

Figure 2. A comparison of affordances of paper and digital media.

It could be noted that, as far as affordances are concerned, there can be (1) perceived limitations of paper overcome by digital media, (2) perceived limitations of digital media overcome by paper, and (3) perceived limitations of paper not overcome by digital media *and* perceived limitations of digital media not overcome by paper, which is a proper subset of $U - (A \cup B)$. There are several examples of (1), such as automatic archivability, linkability, multimodality, retrievability, searchability, shareability, traceability, updatability, and so on, a discussion of which is beyond the scope of this paper. In addition, quality-in-use requirements are difficult to simulate properly on paper. For an example of (2), paper has a *single* level of abstraction, as implied by Fig. 3, while digital media

has *multiple* levels of abstraction (and, therefore, explicit dependencies), which has consequences for the usage of each. For an example of (3), requirements (such as those about credibility, maintainability, and reliability) that are a function of *duration* (that is, interval of, rather than point, in time) are difficult to simulate properly.

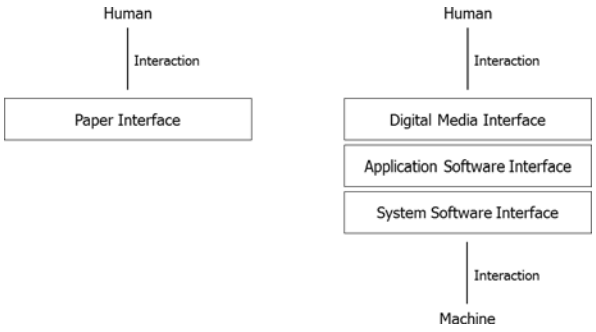

Figure 3. A comparison of levels of abstraction of paper and digital media.

III. A Human Interaction Perspective for Understanding the Use of Paper in REE

A. A Conceptual Model for Human-Paper Interaction and its Implications for REE

Fig. 4 shows a conceptual model in UML Class Diagram for human-paper interaction. The humans have needs, such as those highlighted by the higher levels of the *Maslow's Hierarchy of Needs*, some of which can be educational, as shown in Fig. 5. To satisfy those needs requires humans to draw upon (declarative and/or imperative) knowledge, which in case of REE is summarized in Fig. 6. This is then used to engage in one or more individual and/or social activities as, for example, explained by the *Activity Theory* [21, 22], in general, and the *Bloom's Taxonomy* [23], in particular. To make the communication or knowledge inherent to these activities explicit, they may need to be expressed in one or more artifacts, which could be made of some material, such as paper.

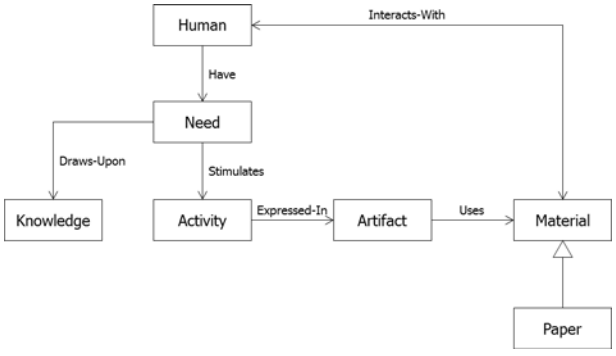

Figure 4. A conceptual model for human-paper interaction.

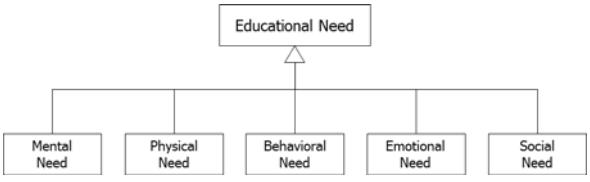

Figure 5. A hierarchy of educational needs.

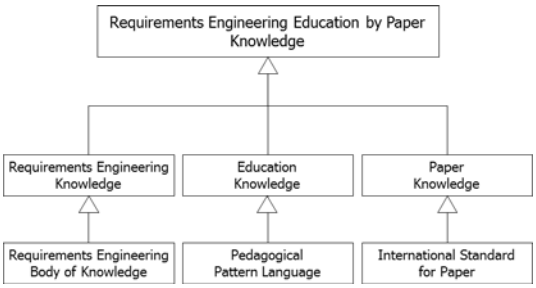

Figure 6. A hierarchy of REE by paper knowledge.

B. Paper Types Suitable for REE

There are many types of paper (https://papersizes.io/), of which some have been empirically proven to be useful in RE. The types of paper useful for REE can be either *generic* or *specific*, instances of which are shown in Fig. 7 and Fig. 8, respectively. The generic types of paper are broad in their applicability, and the mapping between the set of REE activities and the set of paper is many-to-many. The specific types of paper are narrow in their applicability, are available as device-specific templates, and the mapping between the set of REE activities and the set of paper is, essentially, one-to-one.

Figure 7. A collection of generic paper types relevant to REE.

Figure 8. A collection of specific paper types relevant to REE.

Fig. 9 highlights those properties of humans and paper that are relevant in human-paper interaction. For a given activity, selecting an appropriate type of paper is therefore important.

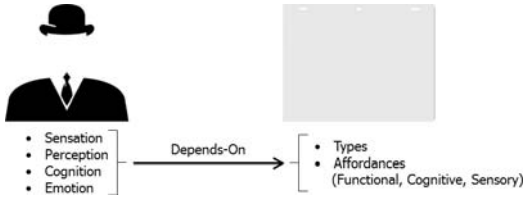

Figure 9. The human and paper properties in human-paper interaction.

C. A User Story Process Model for the Use of Paper

In general, a RE process is independent of the use of any particular tool, including paper. However, certain RE processes, especially those that are agile, human-centered, and informal, may be better suited to the use of paper than the others.

The user stories are one of the most common ways of expressing software requirements in human-centered agile methodologies [24]. Fig. 10 illustrates a user story process model that has been used for REE [25], the elements of which, namely *Express*, *Experiment*, and *Evaluate*, are extended, as appropriate, using the stages of design thinking, namely *Empathize*, *Define*, *Ideate*, *Prototype*, and *Test* [12], so that it becomes conducive to the use of paper. The symbol ► denotes the need for *convergent thinking*, while ◄ denotes the need for *divergent thinking*. The resulting model is aligned with the REE concepts given in the rest of Section III.

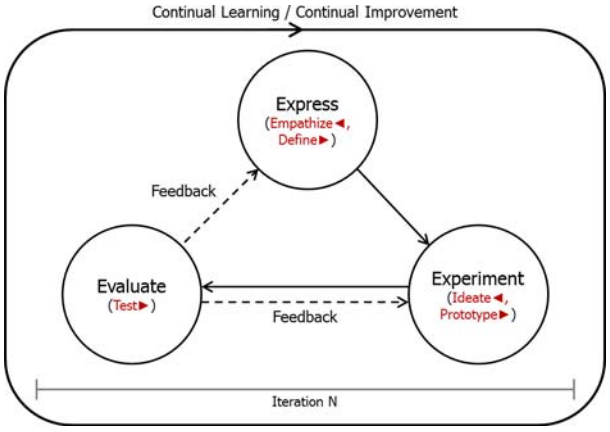

Figure 10. A user story process model conducive to the use of paper.

D. Implications of Paper for REE

The use of paper opens new vistas for REE, such as the following:

- **Silver Lining.** The perceived limitations of paper for REE (and beyond) can also happen to be its benefits. For example, the constraints of size (dimensions) of an index card compel a writer to be concise, which is recommended for user story and its acceptance criteria. The need to handwrite or draw for the others to be able to read and understand in a timely manner also obliges the writer to do so (or, if necessary, improve his or her handwriting and drawing skills accordingly), which are desirable lifelong skills for students.
- **RE Without Borders.** It is important for the students to understand that stakeholders of a software project usually include non-technical stakeholders who cannot be reasonably expected to be familiar with (or should be trained in the use of) digital technologies or tools used for software development. For example, non-technical stakeholders can include subject matter experts, business people, and potential end-users. The use of paper presents a low barrier of entry and fosters "democratic", "inclusive", and participatory design through face-to-face collaboration between technical and non-technical stakeholders.
- **Thinking and Doing in Tranquility.** The use of paper allows a person to dedicate time to think and concentrate on the matter at hand. (This is a consequence of Fig. 3.) There are no extra actions (no clicking, no loading-and-waiting, no panning, and no zooming) and no distractions (no advertisements, no clearing cache, no connectivity, no electrical power loss, no emission of heat or light, no error messages, no glare, no multitasking, no noise, no pop-up windows, no spellcheckers, no updates, and no viruses).
- **Creative Freedom.** The use of paper permits a person to draw freely, limited only by imagination. For example, there are no limits to the shapes and symbols such as those that could be used in a "boxes-and-lines" diagram, or, if necessary, invented "on-the-fly" such as while brainstorming or sketchnoting. There are also no a priori restrictions on where any text labels could be placed or how they may be spaced.
- **Preserving Memory of Mistakes.** In the use of paper, there is no "undo". The use of paper leaves physical reminders of any mistakes made by its user, however minor they may be, even if an eraser is used. These reminders can serve as evocative aides-mémoires of the quote "to err is human", RE smells or anti-patterns introduced and removed after 'iterative improvement' [26], and/or acknowledgement of 'lesson learned', hoping to not repeat the same or similar types of mistakes again. This—embracing and learning to live with one's mistakes—is crucial to lifelong learning of students.
- **Sustainability Lessons.** In software development, there can be different kinds of waste [27], including that of time and effort, such as due to rework. The provision of paper-based prototyping and feedback can help detect and correct certain types of errors early, thereby reducing rework later. The cost of paper and its impact towards environmental sustainability [28] can be a reminder to the students not to waste space and to use it conservatively, such as by using both of its sides. The waste of any kind should be discouraged and prevented, not least because it is one of the principles of *lean software development*. The movements such as the *World Paper Free Day*—an annual campaign that aims to reduce the amount of paper generated by people in their everyday work and personal life—should be encouraged and supported. The same applies to the *International E-Waste Day*. Indeed, these can be part of lifelong learning for students.
- **Preventative Approach to Development.** The use of paper enables getting the *right design* (validation) before getting the *design right* (verification). It is relatively easy and inexpensive to produce multiple design alternatives. (The need for delving into design in RE arises when undertaking a "wicked problem" where the act of finding a solution to the problem improves the understanding of the problem itself.) If a low-fidelity prototype is not accepted during user testing, chances are high that the end-product will not be accepted either.

- **Social Context.** The use of paper cultivates a natural environment for necessary socialization among stakeholders (including students) of a software project. For example, it can be used for meeting, discussing, and/or decorating in front of a Kanban board for showing the different *states* of work-in-progress in a hallway or in a classroom; planning poker using special-purpose playing cards for estimating user stories by stakeholders sitting around a table; and so on.

Incidentally, these observations contribute to REE by Paper Knowledge, as shown in Fig. 6.

E. REE Concepts in Practice on Paper

The REE concepts (interspersed and interrelated *activities* in a RE process and, possibly, *artifacts* resulting from those activities) are motivated by educational needs (as per Fig. 5). They could be divided into *primary concepts* (part of a RE process directly, and abstract) and *secondary concepts* (part of a RE process indirectly to support one or more primary concepts, and concrete).

The primary REE concepts include: active learning, collaborating, creating, discussing, empathizing, enjoyable learning, ensuring semiotic quality of software requirements (such as resolving ambiguities, inconsistencies, and indeterminacies), group learning, team building (norming stage to performing stage in the *Tuckman Model of Group Dynamics*), incrementing, iterating, negotiating, planning, problem solving, reading, thinking aloud, user testing, and writing.

Table 1 shows secondary REE concept(s), corresponding paper type(s), and supporting reference(s), wherever available. The symbol 'S' denotes the use by students in a course project.

TABLE I. SECONDARY REE CONCEPTS ON PAPER

REE Concept	Paper Type	Reference
Brainstorming, Computational Thinking, Doodling, Ideating, Mind Mapping, Sketchnoting	A, A1, Napkin	[7, 29, 30], S
Conceptual Modeling, Domain Understanding (Deciding Terms and Definitions for Software Project Glossary)	Sticky Note, A1	[7], S
Context Diagramming	A1	[31], S
Affinity Diagramming (Post-Requirements Elicitation Interview Analysis)	Sticky Note	[7, 32, 33], S
User Modeling (Eliciting Positive and Negative User Roles)	Sticky Note	[7], S
Empathy Mapping	A	S
Documenting User Stories and Acceptance Criteria	Index Card (Two Sides)	[7, 24], S
Estimating User Stories (Planning Poker)	Playing Card	[24, 34], S
Prioritizing User Stories	Index Card, Sticky Note	[24, 34], S
Customer Journey Mapping, User Story Mapping	A1	S
Information Architecting, Low-Fidelity Rapid Prototyping	Device Template, Grid, Kami, Ruled	[21, 33, 35, 36], S
Kanban Boarding	A1, Index Card, Sticky Note	[13]

IV. DIRECTIONS FOR FUTURE RESEARCH

There currently is no 'standard' RE pedagogical strategy, although there have been a number of notable initiatives over the years [2, 4]. There are also several possible paths through RE, which is why there are multiple possible courses on RE. For example, while one course may be oriented towards formal specifications for mission-critical systems, another may be oriented towards user stories for socio-technical systems. It would be useful to explore the variability in the use of paper with respect to different pedagogical strategies and different syllabuses in REE, and is therefore of research interest.

In Winter 2018 and Fall 2019, a survey on the use of paper in RE was conducted, the results of which were used in [7]. The respondees were graduate students in the course titled *SOEN 6481* (*Software Systems Requirements Specification*). The responses regarding preference for paper or digital media for RE was mixed. The comments from the students included: "*I have learned different uses of colored paper*", "*I have become better at reading others' handwritings*", and "*I was occupied enough with paper to not miss my smartphone!*". It would be useful to extend and repeat the survey, both during and after the COVID-19 pandemic, with both teachers and students of RE, and is therefore also of research interest.

V. CONCLUSION

The rich history and salient properties of paper make it uniquely suitable for a variety of REE-related activities, as this paper has shown. The circumstances presented by the COVID-19 pandemic have led to a notable decrease in face-to-face social interaction. These circumstances, invariably, have also necessitated, even accelerated, the use of digital media for some, a trend that may only continue, to which REE is not immune. This movement, however, should not come at a cost of use of paper. Indeed, the two can coexist [37, 38].

In conclusion, for teachers of RE there are following recommendations:

- **Recommendation 1: Careful Substitution.** There are no 'perfect' tools, tools are not substitutes for people and processes, and tools can aid, but are not a substitute for, thoughtfulness. Therefore, the students could be warned against the misconceptions and myths surrounding tools [8, 14], as well as drawbacks of shallow comparisons and impetuously-drawn sweeping conclusions regarding tools. The availability of digital LEGO® bricks (such as by using *LEGO® Digital Designer*) has not stopped the sale and use of physical LEGO® bricks. Similarly, the availability of interactive whiteboards has not made conventional blackboards useless or the students any smarter [39]. In accordance with building a pedagogical foundation for RE, it is only in students' interest to avoid being enamored by any particular tool and become *polyliterate*: learn to select multiple different tools, each based on its own merit, and learn to use them properly.
- **Recommendation 2: Spirited Cooperation.** The problems being addressed by software systems today have become so large and complex that they are not in the purview of any single individual if they are to be solved

within the given time and other constraints. Therefore, the students could be presented with opportunities not only to work collectively, but also to candidly review each other's work so that they can learn from their own mistakes as well as that of the others.

- **Recommendation 3: Rigorous Experimentation.** There are many possible views of software engineering, one of which is that it is a risky endeavor. Taking reasonable risks not only requires curiosity, but also courage to make mistakes early, and to learn and recover from them. Therefore, the students could be encouraged not only to seek the *known* iteratively and incrementally, but also the unknown and even the *unknowable* [40], all the while understanding the differences between them.

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