What Makes It Hard to Apply Software Product Lines to Educational Technologies?

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Abstract—In this paper, we present our experience of mining a software product line (SPL) from 9 existing eLearning systems developed at 9 different locations by 9 different teams following 9 varied development processes over a decade. The goal of this family of eLearning systems is to address 287 million adult illiterates in India spread across 22 Indian languages. This presents a unique and challenging situation as the SPL arises from a societal context rather than a business context as in traditional SPL. We explain the context of this domain and present the key challenges of mining an SPL from these eLearning systems. The main intent of this paper is to present our journey of applying SPL to these legacy eLearning systems in the last six years. Finally, we briefly discuss the ideas of Lean Software Product Lines and Global Software Product Lines as two potential future research directions for the SPL community.

Index Terms—Software product lines, lean, agile, educational technologies, eLearning systems, global software development.

I. INTRODUCTION & MOTIVATION

How to reduce the massive effort for developing and maintaining educational technologies to support different levels of education like language literacy, school education from K1 to K12, engineering education and so on?

One of the major factors for restricted use of technology in education today is mainly because of the enormous effort and the ever increasing complexity of educational technologies. This is further aggravated by the need to customize these technologies for a wide range of different contexts based on socio-cultural, economic and political factors. However, this significant challenge of reducing effort for developing and maintaining a large scale of educational technologies is often considered as content and infrastructure management in the Technology for Education (T4E) community [1].

On the other hand, there has been empirical evidence of improving productivity by applying SPL to a wide range of domains [2] [3] and in the context of this paper, we are interested in eLearning systems as a case of educational technologies. However, there are few efforts in the SPL literature focusing on digital information products similar to eLearning systems [4]. Most of the existing efforts focused on systems that involve code components whereas the eLearning systems in this paper involve multimedia components like visual and sound elements. An interesting work in the context of accelerating multimedia applications was presented in [5].

In the last six years, we have applied software engineering ideas and continuously tried to accelerate the development and maintenance of a family of eLearning systems for adult literacy in India [1] [6] [7]. The main thrust of this paper is to unveil the experiences, challenges and lessons learnt during this experience from an SPL perspective.

- We present an interesting real-life case study from the domain of eLearning systems (Section II).
- We summarize our approach and experiences towards automating the development of a family of eLearning systems (Section III).
- We outline the key challenges of mining an SPL from these legacy systems (Section IV).
- We briefly discuss Lean SPL and Global SPL as two potential future research directions (Section V).

II. THE ALP CASE STUDY

There are nearly 287 million adult illiterates in India spread across 22 Indian Languages and who are unable to participate in this knowledge-driven society [8]. National Literacy Mission (NLM) took a major initiative to address adult illiteracy in India and devised a uniform approach applicable to all Indian languages [9]. Tata Consultancy Services (TCS), an Indian software house offered a computer based technology solution called Adult Literacy Programme (ALP) [10] based on learning methodology and instructional material from NLM.

Development of ALP eLearning systems (hereafter simply referred as eLearning systems or systems) has involved collaboration from instructional designers, software developers, government authorities and many others including researchers. The development of eLearning systems for Telugu and Tamil language has started in 2001. While both of them are based on NLM’s learning methodology and instructional material, these eLearning systems are tailored based on culture, content and local requirements of learners. Both systems have their own development and field team who were instrumental in constructing the software and ensuring that software was deployed on the field. Despite their success on the field and collaborations between Telugu and Tamil teams, both structure and software development processes of these systems differed and often led to several inconsistencies. In both cases, field trips with actual deployment of software have triggered continuous changes to the system requiring further effort.
We have similarly analyzed the development of another 7 eLearning systems developed by different teams at various locations. Figure 1 shows the screenshots of all 9 eLearning systems developed by TCS for over a decade. Even though this experience has shown the efficacy of using technology for adult literacy [10], from a software engineering perspective, the efforts for development and maintenance of these systems have been quite high in additional to the following challenges [6]:

- Lack of a consistent product structure and software development process across all eLearning systems.
- Lack of availability of standard components for assembling and customizing eLearning systems.
- Reinventing the wheel for every eLearning system in terms of domain understanding and development.
- Sharing of knowledge and transfer of ideas between different teams of eLearning systems was difficult.

Technically, the challenge comes from the need to develop and maintain eLearning systems for a large scale and variety of systems with lot of constraints and societal context which are discussed in Section IV and further elaborated in [6].

![Fig. 1. Screenshots of 9 eLearning systems [6][10]](image)

### III. AUTOMATING THE DEVELOPMENT OF ALP eLEARNING SYSTEMS USING SOFTWARE ENGINEERING IDEAS

During our analysis of eLearning systems in ALP initiative, we observed that the software development process is sporadic, unstructured and often led to redevelopment. The eLearning systems addressing the rest of the Indian languages (13) have to be developed from scratch and delivering these systems in any Indian language dialect as medium of instruction further increases the scope of ALP. With the earlier experiences of developing and maintaining a single eLearning system taking 5 to 6 person-years [6], the effort to develop and maintain this huge scale and variety of eLearning systems is enormous. There are several possibilities open that extend the original scope of ALP. An ALP eLearning system can be adapted to teach in any Indian language dialect, so that migrants from other linguistic regions could learn using the local language. Those who are not familiar with any Indian language could learn a language using an English version of the system. Considering the effort of 5 to 6 person-years for each of the

![Fig. 2. Key aspects of TALES approach](image)

eLearning systems, development and maintenance of these systems at such a mass scale and huge variety is enormous.

To address this massive challenge, we turned to traditional manufacturing for inspiration and adapted mass customization from there. Even though there are lot of commonalities between manufacturing and SPL, there was reluctance to the former while the latter received good attention from the community [11]. We have argued that the reluctance to acceptance of applying manufacturing ideas to software is mainly because of the context in which they are applied [6]. We have devised an approach Towards Automating the development of a family of eLearning Systems called TALES that integrates ideas from manufacturing and SPL [6]. This approach has resulted in reducing development effort of ALP eLearning systems from 5 person-years to 5 person-months [6]. Figure 2 details the core activities of TALES approach that forms the basis for developing the entire family of eLearning systems. The first step is to understand the problem domain and identify the commonalities and variabilities. Then, we have essentiality applied two core ideas: Standardization (product structure, production process and raw material), during which we have developed an underlying standard platform that exploits the commonality of the problem domain and provides mechanisms for producing the required variety of products; and Virtual Assembly Lines, that exploits the standard platform and composed of production processes weaved with tools to automate development. The TALES approach based on these ideas and specifically designed for eLearning systems has resulted in a 10-fold productivity improvement [6]. A few insights and lessons learnt from this experience are:

- Experience of developing products manually is an important pre-requisite to facilitate automation.
- An underlying theory for a family of products is crucial
for understanding and analyzing a domain (the uniform approach from NLM has helped us in the case of ALP).

- Building a standard platform requires a deeper understanding of software development processes at operational level with an eye for granular detail.
- Automating software development processes requires explicit modeling of processes at coarse level of detail.
- Tools bound by processes and processes composed using assembly tools are vital for automation.
- Reusing repositories of components, tools, and processes speeds up the automation process.

IV. KEY CHALLENGES

How can we address the scale and variety issues during the development and maintenance of a family of eLearning systems? We believed that SPL can significantly provide a feasible solution. However, we have faced a number of challenges that require further research from SPL community.

A. Societal Context Vs Business Context

How does the notion of SPL change in a societal context rather than a business context? What is the motivation and how can a business case be established?

While SPL literature has seen many successful cases when there is a strong business case, we are not aware of how to establish a business case for SPL in a societal context. A societal context essentially means that the need and motivation for SPL comes from societal problems as explained in Section II. They generally emerge from corporate social responsibility (CSR) initiatives of organizations (for example, ALP is a CSR initiative of TCS) or from voluntary organizations. It has been continuously observed in the management literature that establishing a business case for CSR is extremely complex since it is reliant on a number of factors (like economic, ethical, political, social) that even influence the survival of CSR initiatives [12]. In our experience, we have observed that justification for SPL in a CSR initiative is much more difficult as it not based on just technical and managerial aspects but is also influenced by diversified stakeholders who are indirectly associated with the initiative. For example, government can influence and put down the direction of SPL for adult literacy even without citing the reasons. While we believe that SPL adds value in a societal context, we are seeking directions for adapting existing SPL approaches to fit in this context.

B. Dealing Non-Technical Stakeholders

How can we deal with non-technical and diversified stakeholders during design and development of SPL?

Most of the stakeholders in ALP and T4E space are non-technical people and are from diversified backgrounds. There were instructional designers who focused on instructional material, government officials who were interested in how this SPL would benefit society and education policies, NGOs in education sector, and technologists who actually build the eLearning systems. During this interaction, our main challenge was to communicate with these stakeholders and convince them that SPL is a good idea. We have used feature models and presented business case to the stakeholders but we are unable to convince them as value for each of the stakeholders is different. For example, an instructional designer was unable to clearly specify the features (learning goals, methodologies, learner profiles and so on) of his instructional design. The diversity of stakeholders made the communication among them quite difficult. It was even difficult to come up with core and variable features because of different terminologies used.

C. Cross Organizational SPL

How to design an SPL that spans across different organizations from different domains?

While there is extensive use of SPL approaches in a single organization, there are few cases of creating an SPL across multiple organizations with diverse backgrounds (like ALP case study). We found that a strong business case alone itself is no longer sufficient to motivate for SPL and it is rather hard to convince all the organizations to devote resources to SPL unless the specific benefit for each of them is shown upfront. We have used reactive and light-weight approaches for SPL to bring down upfront investment however it was difficult to do it because of variations across organizations. We see that the ancillary and supply chains of manufacturing have their product lines spread across organizations. Even though we see various components of software often come from multiple organizations, we see the need to further investigate SPL approaches for cross organizations across domains.

D. Globally Distributed Software Product Lines

How to develop SPL in a globally distributed environment?

Educational technologies of ALP and T4E domain have to be developed in a globally distributed environment because of the nature of the domain and the existence of multiple languages (22) with varied content. We found that development of SPL at a centralized location is practically unfeasible for ALP because there is a need for experts at different locations to continuously customize and improve the product based on feedback from on-the-field deployment. We have also observed that human aspects and communication, co-operation, co-ordination and collaboration among diversified stakeholders is a major challenge in itself in a globally distributed environment for SPL. While there are few emerging efforts like [13] towards this direction, we see the definite need for further research.

E. Process Diversity & Version Management

How can we map the diversified processes during the development and maintenance of SPL?

We found that there are multiple diversified processes during the development of SPL for ALP. We have mapped our technology development process to government’s teaching process, collaborated with TCS who have their own development processes and as researchers we have our own process. We have faced a major challenge because we have 22 eLearning systems of an SPL spread at different locations with unstructured and varied processes creating inconsistency across the systems. On the other hand, we found it quite difficult to manage different versions of ALP eLearning systems as varied processes and tools are used for version management.
F. Domain Specific Challenges

How to address the specific challenges that arise from the domain during the development of SPL?

We observed the following major challenges in ALP case study and T4E domain (i) Informal and evolving domain models – We found it difficult to identify and model various features of ALP case study from diversified stakeholders because of the informal and non-technical background of stakeholders. For example, according to a government official, “We persuade learners to come to centers to learn by giving them incentives” is an important feature for ALP eLearning systems. Technically, this can be achieved through a set of motivational videos and customized stories of local people who became literate and made their life successful. It is difficult to map this feature to cognitive background and mental models of learners which are required for an instructional designer (ii) Invisible variability – We also found that despite several attempts, it is difficult to identify variabilities for educational technologies as stakeholders from learning methodologies, technologies, software engineering and HCI have their own viewpoint and use different terminologies for the same content and are often least interested in other viewpoints (iii) Updating on-the-field product is another major challenge and so is the modeling of domain without requirements and documentation.

V. FUTURE DIRECTIONS

We envision the following potential future research directions for addressing challenges in the SPL community.

Lean Software Product Lines: In the recent times, there has been extensive research on making SPL more light-weight and agile. However, there are still open research challenges for applying agile SPL to large scale projects. It is here we propose that integrating lean ideas like 7 lean principles, 5S, value stream mapping into SPL can address the potential issues in agile SPL. The core idea is to broaden the scope of agile SPL into lean SPL and address key challenges. We have briefly discussed the idea of Lean SPL for eLearning systems in [1].

Global Software Product Lines: The emerging need to develop SPL in a collaborative and globally distributed environment calls for researching approaches that integrate global software development into traditional SPL approaches.

Ontological SPL Engineering: Even though researchers have tried integrating ontologies and SPL [14], there is sparse research on utilizing the power and capabilities of ontologies for modeling and communicating knowledge in SPL.

VI. CONCLUSIONS

The work presented in this paper is based on observing, analyzing and improving a concrete real-life case study from eLearning systems domain for over 6 years. We outlined the key challenges while transitioning from stand-alone to SPL. We briefly summarized TALES approach as an integration of ideas from traditional manufacturing and SPL. We discussed the key challenges of applying SPL to eLearning systems: societal context, dealing non-technical stakeholders, cross organizational SPL, global SPL, process diversity and version management along with domain specific challenges. One interesting point we would like to emphasize is that designing SPL for ALP and eLearning systems in general has many non-technical issues at a higher level which need further investigation. Finally, we hope to trigger a fruitful and rigorous discussion in the SPL community and drive them towards the potential research directions of Lean SPL and Global SPL.

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