Curriculum Ergonomics: A Rich Task Experience From An Asian Perspective

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Abstract

Curricula in different places of the world are consistently undergoing changes and reforms to meet the capacity needed for citizenship of the 21st Century. Applying the idea of HFE to Curriculum Ergonomics, design of interventions in curriculum should with best efforts aim to fit the users (teachers and students) for creating an optimal enhanced learning environment. The aim of this paper is to illustrate how a curriculum intervention may be designed towards this end via the lens of Human Factors / Ergonomics (HFE). The Rich Task project in Hong Kong was a two-year project involving 13 schools and 27 teachers and 46 lessons. Via an analysis of the nature of interaction in the university team-teacher-student (UT-T-S) artifacts in the project with a participatory approach, the findings showed how the teachers varied different factors in the design process to cater for the diverse students' ability and the indicators for successful implementation of the "rich task" lessons. Finally, the authors propose to include curriculum ergonomics in the future agenda of teacher education.

Keywords: Ergonomics; Participatory Ergonomics; Education; Co-operative Work; Rich Tasks; Mathematics Education.

1. INTRODUCTION

> "The focus of HFE is to jointly improve performance and well-being by designing the integrative whole better, and by integrating the human into the system better. This is done by fitting the environment to the human." [1]

In an era of rapid development of knowledge and technology, curricula in different places of the world are consistently undergoing changes and reforms to meet the capacity needed for citizenship of the 21st Century. Applying the idea of HFE by Dul, et al. [2] to curriculum, the design of an intervention in curriculum should with best efforts aim to fit the users (teachers and students) for creating an optimal enhanced learning environment. In the case of a curriculum intervention, the participant teachers often become the key stakeholders for decision making of what design is most benefit their students, for this reason the participatory approach becomes relevant. The aim of this paper is to illustrate how a curriculum intervention may be designed towards this end via the lens of Human Factors / Ergonomics (HFE) and participatory ergonomics.

The mathematics curriculum in Hong Kong has been going through reforms for the last three decades and the current position is that "Students require knowledge and skills that will help them live a full life in the society of the 21st century" [3]. In reality, the ideas of recent curriculum reforms in Hong Kong often are a result of new pedagogical models and orientations originated in the west. In addition to the long established Confucian heritage embedded in the Chinese pedagogical culture in the Asian region [4], the phenomenon of consistent outstanding mathematics performance of Hong Kong students in international comparative studies, such as TIMSS [5] and PISA [6], undesirably poses extra worries and cautions when teachers implement new approaches, thus creating a dilemma in promoting changes in curriculum reforms in a local context. What is the dilemma? Although mathematics teachers are aware of the need to accommodate change for helping students develop the 21st century skills such as collaborative and communication skills, research shows that the mathematics teaching in Hong Kong in general remains directive, relying heavily on traditional conceptions of "effective" practices leading to good achievements [7]. Therefore, the reports of good news of students' achievement in some way raise the tension of innovations at the classroom level. For instance, mathematics teachers often worry that change the pedagogical approach may result in insufficient teaching hours to cover the stipulated content in the curriculum, while without envisaging a raise of students collaborative and communication skills. Hence, for the enacting of new pedagogical approach in the curriculum, it is essential that teachers leverage their professional and intellectual skills in collaboration with multiple stakeholders such as university educators and researchers.

1.1 The Aim of The Paper and The Research Questions

The aim of this paper is via an ergonomics lens to describe a professional-learning-community-based (PLC-based) project encouraging the implementation of rich tasks in classrooms in Hong Kong. The Rich Task Project we reported in this paper situated in the context of Hong Kong and has achieved empirical successful experiences with confirmation by the participating teachers while addressing the issue of catering for student learning diversity. How may this be achieved? The Rich Task Project PLC model consisting of the university research team and participant teachers provides a guideline for the essential categories of professional activities, however, the PLC model does not provide a structure for interpreting the intervention procedure, especially, lacking the details of the interactive process between the people and the resources in the processes of design and enactment. The analysis via the lens of ergonomics here plays a complementary role to the PLC model, hoping to shed lights on the factors for bringing about successful curriculum intervention from a nuanced perspective.

Access to resources not necessarily brings about learning [8]. Applying a framework of ergonomics, the analysis of the interaction between the different elements in the project aims to demonstrate how the enactment of the project may address the issues of catering for diversity and bringing about successful lessons during implementation. The analysis of the Rich Task Project in this paper puts the focus on the interaction between the people and the resources, specifically,

(i) How did the university team (UT) and teachers interact to design rich task to cater for student learning diversity?

(ii) What were the indicators of success in the implementation lessons envisaged by the participants (i.e., the teachers and the students) in the project?

1.2 Significance and Outline of The Paper

This paper attempts to make contributions at both theoretical and practice levels. At a theoretical level, curriculum ergonomics is explained in relation to a broader construct of human factors/ergonomics and a multiple dimensional participatory ergonomics framework. At a practice level, via the ergonomics lens, the study gives an interpretation for the factors of a successful professional learning community based curriculum intervention in an Asian context. The findings suggest directions for future interdisciplinary between education and ergonomics.

1.3 Structure of The Paper

In the following sections, the authors will present the theoretical perspectives of the notions of curriculum and curriculum reforms, human factor / ergonomics (HEF) and participatory ergonomics PE contributing to a framework for curriculum analysis based on the notions of HFE and PE; followed by a contextual summary of the Rich Task project in Hong Kong. Then, the sections of findings present an analysis of analysis of the project via the PE framework, University Team-Teacher (UT-T) and Teacher-Student (T-S) for the design of the task and indicators of a successful lesson. Finally, the concluding remarks follow.

2. THEORETICAL PERSPECTIVES

This section based on literature delineates the key concepts in the study: curriculum, human factors/ergonomics, participatory ergonomics and curriculum ergonomics.

2.1 Curriculum

What is curriculum? The meaning of "curriculum" has gone through metaphorical shifts to addressing the question of "what should be taught" [9]. According to Marsh (1997) [10], there are many ways to define "curriculum": as content for what should be taught; as a product that is a document entailing goals, objectives, content, teaching techniques, evaluation and assessment, resources; as a set of performance objectives about student learning; as that which is taught both inside and outside school, directed by the school; and very broadly as what an individual learner experiences as a result of schooling. Marsh further advocated a definition having potential use in practice: "curriculum is an interrelated set of plans and experiences which a student completes under the guidance of the school" (p.5). Further elaboration for the phrase "under the guidance of the school" may lead to interrelated set of plans and experiences, which involves both the students and the teachers, inside and outside the schools. The concept of curriculum is dynamic and comprehensive. What is curriculum? Curriculum, from our point of departure, is broadly interpreted in terms of two levels: the intended level [11] and the enactment level [12]. The intended level refers to ideological goals represented by the objectives and content stated in the official curriculum documents, whereas, the enacted level, the latter also known as implemented curriculum, refers to what actually happened at school levels directly shaping the students' learning experiences. The concepts of the intended curriculum and enacted curriculum are well discussed [13] and differentiated [14]. Very often textbooks [15] and other teaching resources [16] are described as the mediator between the intended curriculum and enacted curriculum, teachers' decision making and actions in using these resource are thus pertinent in shaping the students' experience of learning [17]. To conclude, at the enactment level, it is an extended continuous process that involves interactions or activities between the key stakeholders, teachers and students inside the schools and teachers and other agents outside the schools. During curriculum reforms, other agents outside the schools may include a variety, such as, educators, curriculum officers and researchers, etc. depending on the events and activities at the enactment level. The Rich Task Project discussed in this paper, which is an intervention project carried out via the interaction between the researchers, teachers and students, thus is an incident at the enacted level.

2.2 Curriculum Reforms and Mathematics Education In Confucian Heritage Culture

Curriculum reforms in Asian regions such as Hong Kong can be viewed as a meeting of the cultures between the west and the east. The curriculum indeed has never ceased to change in recent decades. For instance, the mathematics curriculum reforms in Hong Kong have always been under the influence of the international development, and this fact may serve as a window for summarizing a global trend of curriculum reforms from the 1990s to the 21st Century. Since the 1990s, curriculum in different places in the world has advocated an emphasis of the process abilities of mathematical conceptualization, inquiry, reasoning, communication, application and problem solving; the mathematics curriculum promoted in Hong Kong has been very much in line with this global trend. More recently, a new academic structure of senior secondary and higher education has been implemented starting from 2009 and the positioning is to help students develop knowledge and skills for the 21st century [18]. On the one hand, there are many delineations of the 21st century skills [19], these discussions very often include elements of communication, collaboration, critical thinking, creativity and problem solving [20]. In addition, according to Ananiadou and Claro (2009) [21], there are some critical voices arguing for the emphasis on content and that the teaching of skills such as critical thinking or learning how to learn cannot be taught independently outside a particular knowledge domain for students will not be able to apply such skills if they lack the appropriate factual knowledge on a particular domain. On the other hand, although the promotion of collaborative skills at the level of intended curriculum has been well underway, in fact collaboration is not a 'normal' activity of the secondary mathematics classrooms in Hong Kong for the long established tradition in *Confucian heritage culture* (CHC).

Education in Hong Kong and other East Asian regions is often reported to be much influenced by CHC [22], where the teachers' major roles are for providing role models and guidance [23]. The traditional Chinese beliefs of "practice makes perfect" [24] (Li, 2006) becomes the ground for the emphasis of exercises and imitation [25] to serve the purpose of developing proficiency and understanding of the topic [26]. These CHC pedagogical cultures have been reported to be factors for students' good performance in international studies such as TIMSS and PISA, and consequently, Halse (2018) [27] highlights that from outside of Asia there has been an anxiety about the outstanding Asian students' achievement resulting in many attempts of the West to learn from Asian countries. Nevertheless, the scenario is reverse with respect to pedagogy, for an approach such as collaborative learning originated from the West is advocated in recent curriculum reforms. Despite the explicit promotion of collaborative learning at the level of intended curriculum is well underway, reports of effective collaborative learning are scarce in studies of Asian context [28]. Although the theoretical rationale for collaborative learning is well articulated, the actual enactment in schools still very much depends on interventional practice.

2.3 Human Factors/Ergonomics (HFE) and Participatory Ergonomics (PE)

The root of the word "ergonomics" traces its origin in Greek "ergon" meaning work, and it is generally referred to "an applied science concerned with designing and arranging things people use so that the people and things interact most efficiently and safely" according to Merriam-Webster Dictionary. Ergonomics is accepted widely useful in various disciplines such as science, engineering, design, technology and management of human-compatible systems [29] (Karwowkski, 2005). In the presidential address at the 2003 Congress of the International Ergonomics Association, Karwowski quoted the definition for *human factors/ergonomics (HFE)* adapted by International Ergonomics Association:

> "Ergonomics (for human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize well-being and overall performance." [30] (also mentioned in Legg & Jacobs [31]; Karwowski, 2012 [32]).

Karwowski (2012) [34], in his paper, "The discipline of human factors and ergonomics", pointed out that ergonomics theory is concerned with the ability to identify, describe and evaluate human-system interactions. According to Dul and others (2012) [34], "ergonomics" and "human factors" are considered to be synonymous; HFE has three unique characteristics, namely, taking a system approach, design driven and with a focus on performance and well-being, and HFE has the potential to the design of all kinds of systems with people, whereas systems may be work systems, product or service systems, consisting of humans and their environment. There are not many examples in the application in education. According to Woodcock (2007) [35], in his paper "Ergonomics, education and children: a personal view", there are two identified streams of activities forming educational ergonomics, that is, the teaching ergonomics and the design of the teaching and learning environments. The latter refers mainly to the design of the school from the perspectives of school architecture as well as a broader framework, which included the ergonomics of educational facilities, equipment and environments, learning and instructional ergonomics. Referring to schools as a system, Legg and Jacobs (2008) [36] differentiated between *ergonomics in schools* and *ergonomics for schools*. The former has focused on micro-ergonomics issues such as students' desks and chairs, weight of school bags and the problem of musculoskeletal disorders amongst school students. The latter, ergonomics for schools, is an example of macro ergonomics issues such as classroom environments, ergonomics pedagogy, curriculum content and structure. Curriculum ergonomics discussed in this paper belongs to the latter; it addresses the interaction between the people (university researchers, teachers and students) with the elements of the system (design of tasks, concerns for student ability, the time and class management during the lesson, and the relevance to the curriculum).

Another relevant concept is that of *participatory ergonomics* (PE). Participatory ergonomics involves workers in the development and implementation of changes in the workplace, with the underpinning assumption that the workers are experts and in a good position to identify and analyze problems, as well as developing a solution [37] (Burgess-Limerick, 2018). Based on a review of literature, Burgess-Limerick (2018) [38] stated that participatory ergonomics programs have been implemented across a large range of industries and organizations, such as, mining, domestics and civil construction, office environments and other institutions. Participants in participatory ergonomics team in these examples may include workers, supervisors, external advisors, internal specialists and management union representatives. A conceptual participatory ergonomics framework (PEF) validated by Haines, et al. (2002) [39] mentioned in Hignett [40], consists of nine dimensions, namely: (i) permanence; (ii) involvement; (iii) level of influence; (iv) decision-making; (v) mix of participants; (vi) requirement; (vii) focus; (viii) remit; (ix) role of ergonomics specialist. The framework provides a structure and fundamental understanding to facilitate transferring experiences to other settings.

2.4 A Framework for Curriculum Analysis Based On The Notions of HFE and PE

Applying to the enactment level of the curriculum, *participatory ergonomics* is relevant as the teachers are one of the major participants taking up the role of decision-makers in the actual design and enactment of the lessons. Curriculum analysis of the implementation of the Rich Task Project is articulated in terms of the notions of human factors/ergonomics (HFE), participatory ergonomics (PE), and is about the interaction in two layers of artifacts between the mix of participants (the university research team, teachers and students) and the elements in the system. At the same time, the participant teachers were the main decision makers for the adaptation of the tasks and the enactment in the lessons, aiming to bring about better learning for the students in their classes.

A 2-Step analytical framework via the lens of Participatory Ergonomics Framework (PEF) and HFE/Ergonomics was used in the analysis (Figure 2). The 2-step framework aims to facilitate the study of the interactions of stakeholders (namely, teachers and students) with elements that influence the enactment of the curriculum, such as, pedagogical approaches, design and adaptation of resources, fine-tuning of teaching strategies and materials, and classroom environment to arrive at an ultimate goals for supporting students' learning.

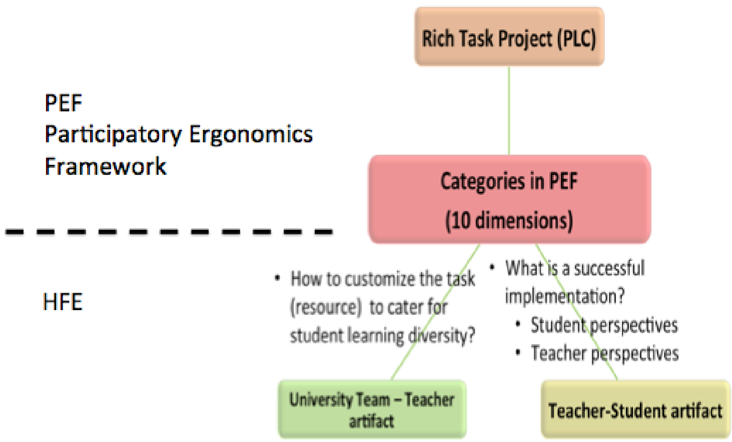


FIGURE 1: A 2-Step framework via the lens of participatory Ergonomics Framework and HFE.

3. THE RICH TASK PROJECT: CONTEXT AND DESIGN

3.1 Some Basic Information of The Rich Task Project

The Rich Task Project was a project for junior secondary mathematics (Grades 7 to 9) with a special aim for *catering for student learning diversity (SL*D), adapting the pedagogical approach of *rich tasks* and *collaborative learning*. The major objectives for the project were: (i) to develop teachers' skills and strategies for designing rich tasks and collaborative learning; and (ii) to enhance students' attitude, motivation and generic capacity for learning of mathematics. "Generic skills" refer to 9 generic skills, namely, collaboration skills, communication skills, creativity, critical thinking skills, information technology; numeracy skills, problem-solving skills, self-management skills and study skills [41]. In particular, what is relevant the mathematics skills in the project are collaboration, communication, critical thinking and problem solving. The implementation applied a professional learning community model consisting of the university research team and participant teachers in 13 schools with students of different standards and backgrounds in different areas in Hong Kong.

3.2 Research Design of The Project

The project was a two-year project involving 13 schools and 27 teachers. There were altogether 46 lessons of rich-task implementation for which the first 13 lessons were pilot lessons for teachers to be familiar with procedures of the rich tasks and the research component. The project took a design experiment approach [42]. The university research team and the participant teachers formed a professional learning community for the project, in which, the rich tasks were designed, adapted with fine-tuning, tried in the lessons, evaluated and further improved and tried in other lessons (in a different class in the same school or another school). For the purpose of evaluating the effectiveness of the rich tasks, the procedure was supplemented with a research component for collecting data for further analysis. All the lessons were video recorded with two cameras with focus on the teacher and on a focus group of two to four students depending on the grouping arrangement in that lesson. All the student work during the lessons such as worksheets and posters were collected for further analysis. The participant teachers and the students were invited for post-lesson interviews. The research component of the project collected data for the evaluation of the success of each lesson that was based on the analysis of the lesson data, the lesson videos, the teacher's post-lesson comments, students' post-lesson interviews and the students' work.

Number of Tasks: To eliminate the language constraints, all the rich task materials were provided in Chinese or English with a brief instruction is attached to every task. A total of 35 tasks were designed, 24 were tried in the schools and by the end of two years, 18 tasks were put onto the website for wider dissemination. During the experimentation, teachers usually made some modification of the basic design of the task to tailor fit their own class. The tasks on the website were all experimented in schools and some had multiple modified versions adapted for schools with different background. Overall, the number of trials for each task varied, the average number of trials per task was 1.9. The task "Sorting Right-angled Triangles" was chosen as an example in this paper for it has been used by 4 teachers in 4 different schools, thus providing multiple modified versions for different student ability as a result of different schools in the region.

3.3 A Theoretical Stance for The Pedagogical Approach In The Project

Student learning diversity (SLD). One of the project aims was to cater for *student learning diversity* (SLD), one of the major local curriculum issues. *Diversity* has traditionally been used to note that individual students (especially due to different levels of attainment) may need diverse resources to encourage their learning. On the other hand, because of the diverse backgrounds of children, their perspectives will be different – and cognitively-based approaches to enhanced thinking requires children to compare their diverse views and accommodate changes for learning to take place. Hence, there are 2 different views of diversity (one based on social class, educational background, etc. and one based on different knowledge exposure). Researchers have shown that dynamical processes in group work and thought sharing are likely to be productive for knowledge creation and learning [43]. The point of departure for *student learning diversity* (SLD) in the Rich Task Project was that students having their own background and experiences inevitably had their own interpretation when they interacted with the learning environment, consequently leading to a diversity of capacity. In other words, in a normal class size of more than 30 students, SLD inevitably existed. In Hong Kong, Junior secondary school was compulsory and remains free for all students. Secondary schools in Hong Kong are categorized into three bands according to their academic standards. Schools with students of higher academic ability were sometimes called the "high-banding schools" [44]. Thus, schools of different social background also provide additional reasons for diversity. Nevertheless, despite the categorization into different banding, teachers often reflected the difficulties to handle students with a variation of mathematics ability in classes while diversity was in general associated with the students scores in tests and examinations. For a point of departure of the project, instead of problematizing the case, the diversity could be capitalized to provide more opportunities of peer learning and scaffolding, via a collaborative learning approach. The professional learning community (PLC) model in the project in particular broadened the sharing of teaching experiences and the variations of student outcomes, hence, providing a ground for better designs.

Collaborative learning is the general pedagogical approach employed in the project. The theoretical stance for collaborative learning is that of the social constructivism rooted in the work of Vygotsky. Vygotsky (1978) [45] describes the idea of the zone of proximal development (ZPD) for describing a learner's potential development. Furthermore, ZPD is not necessary individual, rather, there is a shared ZPD created in the learning activity (mentioned in Lerman [46] and Holton [47]), where students share their ideas and co-construction of meaning in the learning activities. Such interaction may not take place spontaneously in class, for the purpose of creating a collaborative learning atmosphere. In the project, the strategy in a lesson can be described by a briefing-groupwork-debriefing learning spiral [48] (Figure 2).

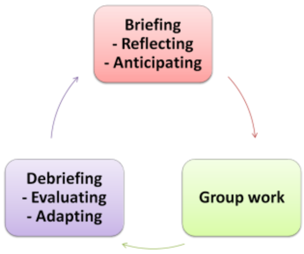


FIGURE 2: Collaborative-Learning spiral promoted within a lesson.

3.4 What Are Rich Tasks?

The idea of "rich tasks" has been well used in mathematics teaching and learning. For instance, in the project NRICH at the University of Cambridge, it is defined as "Rich task have a range of characteristics that together offer opportunities to meet the different needs of learners. On its own a task is not rich, it is how the task is used in the classroom that may make it rich."[49]. For the New Zealand curriculum, the concept of "rich" is associated with a collection of rich learning activities for providing engaging contexts in which to explore the achievement objectives from the New Zealand curriculum [50]. Griffin (2009) [51] in his article, "What makes a rich task?", proposed that the rich learning experience by rich tasks embraced different ways of thinking, such as, classifying mathematical objects, interpreting multiple representations, evaluating mathematical statements, creating problems and analyzing reasoning and solutions, encompassing what are known as mathematical process or mathematical thinking in general. Hence, there is quite a variety of "rich tasks" resources developed in the non-Asian context available on the internet. However, these resources with a variety of styles and contexts, may or may not meet the needs of the curriculum in an Asian city such as Hong Kong for each place may have its own demand on the design of a task [52] for fitting into the cultural/ethnic values in the background [53]. One of the main concerns of the Rich Task Project in Hong Kong is to design rich tasks suitable for the students' need in the local culture, matching the local curriculum and school-based needs. To make a rich mathematics activity, the tasks should be accessible to everyone at the start, so that students with different mathematics capacity have a chance to kick off with the others. At the same time, the design of the tasks need to make room for further challenges and extendible; allowing the students to engage themselves in all kinds of mathematical process well discussed in literature, e.g., Henningsen & Stein [54], Hiebert & Wearne [55], Lester, & Cai [56], Liljedahl [57], and Mason, Burton, & Stacey [58], such as, hypothesis making and testing, proving or explaining, reflecting and interpreting; promoting discussion and communication; hence providing an enjoyable platform for sharing and collaboration. In contrast to the traditional teacher-directive practice in mathematics lessons, rich tasks are designed for scaffolding so that students' ideas can be capitalized and further developed to facilitate further learning.

3.5 Professional Learning Community (PLC)

The term professional learning community (PLC) has been used widely with varying definitions. The key notions of PLC are the notions of *professiona*l, *learning* and *community*.

The notion of community highlights shared beliefs and understandings, interaction and participation, interdependence, concern for individual and minority views, and meaningful relationships. Watson (2014) [59] described PLC as "a means for teachers to engage in professional development leading to enhanced pupil learning." According to Stoll et al., (2006) [60], based on the literature review, there is a broad consensus suggesting an interpretation of PLC as a range of people inside and outside school engaging themselves in in an ongoing, reflective, collaborative process of sharing of ideas related to their practice, mutually enhancing each other and students' learning as well as school development. At the same time, Stoll et al. (2006) [61] proposed five key features of PLC: shared values and vision, collectively responsibility, reflective professional inquiry, collaboration; and promotion of group and individual learning. Spillane, Shirrell and Hopkins (2016) [62] framed PLC as an organizational routine with five essential characteristics: ongoing collaboration among school staff; constant focus on student learning; de-privatization of classroom instruction; reflective deliberations with focus on curriculum; teaching and student learning; and shared norms of collective responsibility for student learning. Stewart (2014) [63] also proposed that the key features in *professional learning activities* in a PLC are content focus, active learning, coherence, duration, and collective participation. Referring to these descriptions, the Rich Task Project was a PLC-based project formed by the University Team (UT), the teachers and the students.

4. FINDINGS: AN ANALYSIS OF THE RICH TASK PROJECT VIA THE LENS OF PEF

TABLE 1: An Analysis of the Rich Task Project with the Participatory Ergonomics Framework.

Dimension	Categories in PEF for industry (Haines, et al., 2002) [64]	Categories modified for the Rich Task Project
(i) Permanence	Ongoing – temporary	Temporary – The project took an experiment design approach and lasted for a 2-year duration while the funding period covered. The dates for the actual implementation of lessons according to the teacher's choice.
(ii) Involvement	Full direct participation – Delegated participation	There were two categories. (i) The teacher first showed interest and sought the principal's approval. (ii) The principal first showed interest and delegated to the teachers. For both cases, the participation was on voluntary basis.
(iii) Level of influence	Group or organization – Entire organization	For each school, only classes selected by the participant teachers joined the project. Consent of the students and parents were sought and the students participated in the project on voluntary basis.
(iv) Decision-making	Group consultation – individual consultation	Group consultation in project: (i) Workshops at the university; (ii) Individual consultation about modification of the designs of the tasks and post-lesson evaluation.
(v) Mix of participants	Operators–Internal specialist–External advisor–Supplier/purchaser	Three levels of participants: • University Team UT (specialist external) • Teacher participants (operators internal / supplier purchaser) • Student participants (end-users)
(vi) Requirement to	Compulsory - voluntary	Participation was voluntary, whereas, all

participate		teacher- and student-participants could withdraw from the project any time.
(vi) Focus	Physical design / specification of equipment / workplaces/ work tasks	Design of the rich tasks and suggestion of how to implement
(vii) Remit	Problems identification – solution development – implementation of change	Actual implementation of the lesson by the teachers
(viii) Role of ergonomics specialist	Initiates and guides process – act as expert – train participants	The University Team UT played the role of ergonomics specialists providing guidance throughout the project, including the design of the tasks, the research component, and consultation
(ix) Possible additions to framework	Embedded participatory structure	There were two artifacts of interaction: (i)The UT-T artifact created between the UT and the teacher in the professional activities, such as, the workshops, the research interface, and dissemination seminars. (ii)The T-S artifact created by the interaction between the teachers and students in the actual implementation of the tasks in the lessons.

Table 1 shows an analysis of the Rich Task Project by applying PEF dimensions. The project can be seen as a multi-level system consisting of interaction at different levels. *The system* consists of the curriculum, the schools and the university where the research project was hosted.

4.1 The People / The Mix of Participants

Following the PEF analysis, the people in *the PLC* formed a *mix of participants* interacting in the university team-teacher (UT-T) artifact and the teacher-student (T-S) artifact. The UT consists of the university educator, project manager and research assistants. UT played the role of the ergonomics specialist responsible for the leadership role and organization role in both research perspectives and management perspectives of the project; they worked closely with the teachers in design of the tasks and was responsible for the analysis of the lessons. The teachers were the voluntary participants in the projects and their knowledge, understanding for the Rich Task Project gradually developed via their engagement in the professional activities. They actively engaged in the decision-making, also contributing to the *focus* dimension for the process of the design and evaluation of the rich tasks. In the remit dimension, the teachers were responsible for the actual implementation, identifying the problems that the students (*end-users*) might have and providing solutions via scaffolding in the T-S artifacts. Through the lens of *curriculum ergonomics,* the main analysis looked into the cognitive aspect of ergonomics, that is, the interaction in the two artifacts with different foci and remit.

4.3 The University Team-Teacher (UT-T) Artifact

The university team-teacher artifact consisted of the communication generated in the training workshops and the communication between UT and individual teachers putting focus on the design of the rich tasks, i.e., how to design and modify a task to cater for different student capacity in different classes. The professional activities took place in the workshops, the research component of the projects, the teachers' sharing in the workshops and disseminations and the teachers' individual communication with UT. These professional activities provides a range of opportunities for essential interaction in the development of the rich tasks, such as incubation of ideas, design of tasks and lessons, sharing of lesson episodes, analysis of students' performance. In addition, there was often informal discussion between UT and individual teacher in the design of the tasks before and after the lessons, thus, UT could had a good interpretation of the teachers' wish lists and help preparing the worksheets and materials for the lesson activities. Furthermore, an additional important aspect of UT-T interaction was contributed by the analysis of the data collected in the research, triangulation of results with the teachers' sharing of results in the workshops.

4.4 The Teacher-Student Artifact

The teacher-student T-S artifact was created as a result of the actual implementation of rich task in the classroom (remit), lesson data of the T-S artifact includes the lesson videos, student work and questionnaire, post-lesson student interviews. Evidence accounting for the success was collected from the teacher-student artifact. The students were the end-users of the rich tasks in the project and the students' perspectives were based on their explicit sharing of ideas and products in the lesson activities, as well as their voluntarily post-lesson interviews. The teachers' perspectives were based on the post-lesson interviews guided with the teacher post-lesson evaluation forms and the teachers' sharing in the workshops. The analysis especially that on the student perspectives was feedback into the U-T artifact to help understand the interactions in the T-S artifact, thus directly supporting the design of the tasks in the UT-T artifact (Figure 3).

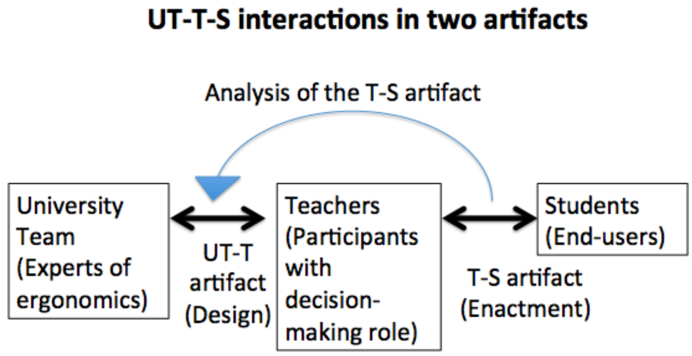


FIGURE 3: UT-T-S Interactions In Two Artifacts.

5. FINDINGS: HOW DID THE UNIVERSITY TEAM (UT) AND TEACHERS INTERACT TO DESIGN RICH TASK TO CATER FOR STUDENT LEARNING DIVERSITY?

Broadly speaking, the UT-T artifact was interaction of the design level and the T-S artifact was the enactment level during the implementation. The UT-T interactions are discussed in this section with respect to three broad stages, the introductory period, the pilot and the implementation, which aimed to achieve different targets in the shared knowledge domain of the project community of university team and teachers.

5.1 The Introductory Period

The introductory period was the period for negotiation of the shared meaning and vision of the project when the UT and the teachers met in the initial workshops seeking for a shared understanding the major concepts and pedagogical approach of Rich Tasks as well as the research element of the project. This period established the fundamental basis for the teacher-participant ownership for the project and the initial mutual trust for later UT-T interactions. A few major concerns were raised in the first introductory:

- What were rich tasks?
- Did they have to design the tasks?
- What would they have to do in teaching the lessons?
- How might they know whether the intervention might benefit their students or not?
- To teach something that are relevant to the curriculum.

These questions reflect the basic dimensions of how the project members developed a shared understanding of the goals and basic concepts introduced by the intervention; the operation procedure of the intervention and how the impact of the intervention might be evaluated. In response to these concerns, the introductory workshop contained: explaining the theoretical concepts to form a basis of future work; the sharing of ideas of using existing resources and relevant teaching experiences; as well as brain-storming ideas for designing tasks. Based on these ideas the UT produced an initial draft of some tasks fitting into the curriculum-matching matrix. For example, the SRT task consisting of the basic concepts of trigonometry and the geometry strand in the curriculum was fitted into the box of geometry-and-basics (Figure 4).

	Algebra	Geometry	Data handling
Basics (skills and concepts)		"Sorting Right-angled Triangles" (SRT)	
Enrichment			

FIGURE 4: The curriculum-matching matrix matching the algebra/geometry/data-handling strands of the local mathematics curriculum.

5.2 The Pilot Period

There was a two-month pilot period at the beginning of the project during which all participant schools were encouraged to try one rich task lesson to get familiar with the procedures of implementation, such as, to teach a lesson with the rich task and collaborative learning approach, collecting consent letters from students and parents, and supporting the data collection procedure. By the end the project, the teachers pointed out that the pilot was essential for they had a better idea of what to do. At the end of the pilot, UT and participant teachers arrived at *an optimal activity-sequence* for the lesson consisting of *two rounds* of group work: introduction, first round of group work and debrief, second round of group work and debrief. The first round of group work would be a kind of warm up and the task should have lower cognitive demand (relatively easy) to ensure that the students could kick off and had a chance to clarify what to do in the initial experience. The second round contained materials with *a raise in cognitive demand* to give a potential extended exploration and discussion.

5.3 Implementation: The 4-stage cycle of idea-customization-trial-evaluation ICTE

The rich tasks were implemented in an idea-customization-trial-evaluation cycle interweaving between the UT-T and T-S artifacts.

1. "Idea" in the idea-customization-trial-evaluation cycle

The very first idea of the task could be adapted from any available resources such as e-resource on the internet. Figure 5 shows an example (the task of Sorting Right-angled Triangle SRT) of an outcome of rewriting the specific objectives of the task and identifying the content focus, using the technique of sorting, matching and poster-making [65].

The specific objective: *"To create a poster by matching the trigonometric ratios with the right-angled triangles"*

The focus of topics: *"The lengths in surds; Pythagoras' Theorem and similar triangles; trigonometric ratios"*

The expected content of the students' discussion:
"Let the students observe and distinguish many trigonometric ratios; discuss the relations between sides and trigonometric ratios."

FIGURE 5: An example of the rewritten content of the task "Sorting Right-angled Triangle SRT".

2. "Customization" in the idea-customization-trial-evaluation cycle

The task in figure 5 was to match two batches of cards containing different right-angled triangles and trigonometric ratios (Figure 5), fitting into the Geometry-Basics box in the curriculum-matching matrix (Figure 4).

The cognitive demand of the tasks had a direct impact on the level of difficulties of the task and the content of the student discussion and it was directly associated with the mathematical content and the number of entities in the matching. Figure 5 shows a few examples:

$$cosx = \frac{3}{2}, tanx = \frac{\sqrt{3}}{2}, tanx = \frac{1}{2}, tanx = 1.5$$

Each of the trigonometric ratios, posed a specific cognitive demand so that there were a range of difficulty based on the teacher's understanding of students' ability in coping with the content. Internal factors of the design are the mathematical content and the number of items in the matching design.

Internal factors

Mathematical content:

- Whether the ratio contains surd or not,
- Whether the ratio is expressed in the form of a fraction or a decimal;
- Whether the ratio exists or not.

The number of items in the matching design:

- The total number of cards for matching in a batch,
- Whether the match was one-to-one or many-to-many.

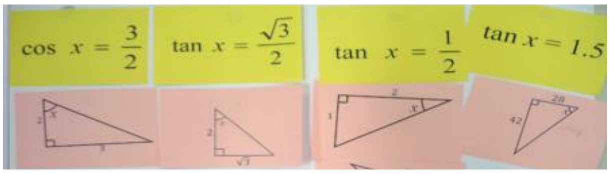


FIGURE 6: Matching two batches of cards containing trigonometric ratios and right-angled triangles.

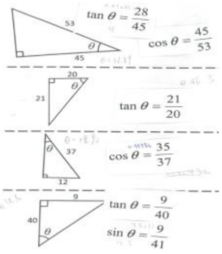
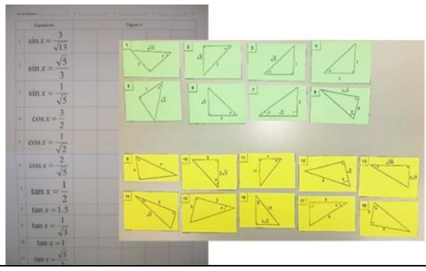
School A	School B
	

FIGURE 7: The tasks in School A and School B (partial view).

External factor: Teachers' decision resulting in variation between different classes

Figure 7 shows the designs used in 2 schools with different student standards when the teacher made the final decision on the design and implemented the lessons.

School A

- Teacher of School A which a lower banding decided to have only one round of group work in the lesson for the expectation that students would need more time to complete a matching.
- He reduced the difficulty by giving fewer triangles (only 12) for the matching, whereas, 10 of triangles contained Pythagorean triples and only two triangles contained surds.
- His students needed to differentiate the right trigonometric ratios and found the unknown side with the Pythagorean theorem, and they were allowed to use calculators.

School B

- The teacher in school B with a higher banding designed a table to present the tasks so that the students would be tidier in making the poster.
- The students were asked to complete the table in two rounds of group work., (8 triangles in the first round, followed by 10 more triangles in the second round).

- The teacher included a lot of items with higher cognitive demands, such as, surds, similar triangles and impossible ratios in the design and calculators were allowed.

To summarize, there were two steps in customization: (1) design of the task based on the mathematics content and the types of matching; (2) the teacher decision in finalizing the task and procedure during the lessons. These adaptations of the tasks directly varied the difficulty and complexity of the tasks and had a direct impact on the interaction in the T-S artifact.

3. "Trial" in the idea-customization-trial-evaluation cycle

The customized task was implemented in the lesson, which was video-recorded for further analysis. The analysis would be shared in workshops and these sharing very often attracted more teachers to try the task in her/his class and produced new versions of the design for varied student ability in other schools. For example, a scaffolding episode in the debrief after group work, where the teacher invited a student to share her thinking on the blackboard:

> "The student explained her group work. In addition, the teacher invited her to talk about cos x = $\frac{2}{\sqrt{3}}$ because her group put no triangles to this ratio. Teacher suggested her to draw a triangle on the blackboard and calculate the third side. As a result, $\sqrt{-1}$ was found." (The researcher's field notes for Figure 8)

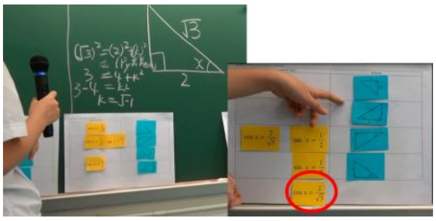


FIGURE 8: An example of a successful scaffolding episode in the debrief of a lesson.

The episode was successful in several aspects, for instance, the students had put focus on an item with relatively high cognitive demand, the students had express their idea and the opportunity of coming to a realization of something new that they might not notice in their early learning experience, and they were applying what they had learnt about the topic to tackle a new case. $Cosx = \frac{2}{\sqrt{3}}$ was an impossible case which teachers seldom used in the traditional paper-and-pencil exercises. However, in the rich task environment, it served as a platform for scaffolding of a deeper understanding of the concepts. Such episode was supporting evidence that the students were well-engaged in mathematical process which was less likely to happen in traditional teaching without intervention. The sharing of episodes as such in the UT-T artifact would raise other teachers' interest in using the tasks for their own teaching and also inspired them how varying some elements of the task might give students an opportunity for extended exploration and expressing their ideas.

4. "Evaluation" in the idea-customization-trial-evaluation cycle

There were two purposes for the evaluation. Firstly, based on the post-lesson teacher interviews and student interviews, the evaluation was shared in the UT-T artifact for further design of the tasks. Sometimes multiple versions of a task were created for different schools and sometimes multiple pedagogical strategies were suggested. The second purpose was to compare between lessons to evaluate what counted as a successful lesson.

6. FINDINGS: WHAT WERE THE INDICATORS OF SUCCESS IN THE IMPLEMENTATION LESSONS ENVISAGED BY THE PARTICIPANTS (I.E., THE TEACHERS AND THE STUDENTS) IN THE PROJECT?

6.1 The Lesson Level

TABLE 2: Indicators of success in the implementation of the lessons.

Student engagement 3 levels:	Communication 2 categories:	Catering for diversity Categories of strategies:
3: Active participation and discussion (> 80% of class time) + showing interest in learning /completing the task + putting effort /persistence 2: Active participation and discussion (> 50% of class time) + showing some complaints / dissatisfaction 1: Active participation and discussion (<50% of class time) + showing fear, giving up and avoidance	2: Encourage student higher thinking 1: Understand and clarify student learning	• Teachers provide different hints • Differentiation of difficulties within one class • Differentiation of difficulties between classes • Open methods or solutions
*Lesson data include the students' presentations, worksheets, students' feedback, learning outcomes, lesson video, observations. Other data are teachers' post-lesson evaluation, students' post-lesson evaluation, researchers' field notes of the lessons.		

Analysis of the lessons was carried out for 3 aspects: student engagement, communication, the teachers' strategies for catering for diversity. The indicators of success were developed for evaluation towards attaining one of the project aims, "to enhance students' attitude, motivation and generic capacity for learning of mathematics", based on the students' work and engagement during the rich task lessons. Three questions were applied as *the conceptual tools in the analysis* and each lesson was coded qualitatively with the indicators shown in Table 2.

The conceptual tools in the analysis for the T-S artifact:

- To what extent are the students engaged in active discussion?
- What are the nature and content of the teacher-student and student-student communication in the lesson?
  What are the teachers' strategies for catering for students' learning diversity?

6.2 Teachers' Perspectives

The teachers were the active participants in the intervention as well as a key stakeholder. How teacher viewed the outcomes of their implementation were important indicators in the evaluation. There were three teacher-participants from the school B that was a high-banding school. However, according to the teachers, some students being less attentive in class and having poorer examination results were usually seen as weak students while comparing with other students of higher capacity. Two of the teachers mentioned in the interviews that their own teaching was traditional and one-way transmission, and all three of them highlighted that they witnessed the improvement of the weak students in the rich task lessons.

> "Out of my expectation, weaker students and those students that used to have problems paying attention have shown increased enjoyment in this type of lessons." (Teacher X)

> "I discovered that those students who used to not expressing themselves during the class started to share their mathematical ideas in the lesson. As a result, I have gained insights on what mathematical concepts my students have learned through the use of a task." (Teacher Y)

> “Before the implementation, I thought that my students were very weak in understanding abstract mathematical concepts, and they were incapable to link different topics in their minds. However, through this Rich Task project, I realized that their minds worked automatically and my students were capable to create links to connect different topics by themselves. … Once their thinking being visible, we realized that they had learned a lot.” (Teacher Z)

In the teacher’s post-lesson evaluation, for a 5-point scale (1- the lowest and 5 – the highest), the teacher rated “2” for the students’ mathematics ability, ability to explain their answer mathematically and problem solving skills. However, the teacher rated “4” for “the students’ enjoyment of the task”, “group discussion involve mathematical reasoning and debating” and “the majority of the students talk on the task”, hence, the lesson was very successful in raising the students’ engagement in doing mathematics from the teacher’s perspective. The strengths of the lesson were that they had tailored the design for the students and that the task could help the students apply the topics in different chapters and provide an opportunity for the students to recognize the connection between the mathematical ideas in the different chapters.

With respect to the question, “What key questions did you use to guide the students to think mathematically and to solve the task with different approaches?” The teacher mentioned support of both the implicit and explicit forms. Referring to the implicit, the mathematics teacher team had a discussion before the implementation and they invented a format: numbering the cards with the triangles and printing a large table for the students to write down the answers (Figure 7, School B). The invention had successfully removed the need of cut-and-paste of paper, reducing the real time for producing the poster. Referring to the explicit, there were a few strategies:

(1) Suggesting a relevant basic skill: When the students were struggled to distinguish the two diagrams to the corresponding equations, the teacher would advise the students to try drawing their own triangles. To draw a right-angled triangle from a given trigonometric ratio was a very basic exercise item for the topic of trigonometric ratio.

(2) Encouraging the students to revisit their outcomes for a deep learning: The teacher also recommended the students to look for some special features (such as ratios, congruence or similarity) when some students could find one equation with two or more suitable triangles.

(3) Giving support for students’ articulation of ideas: When some students forgot some mathematical terms, she would suggest the first letter of the words, like “c” for congruent and “s” for similar, in order to assist them to articulate their ideas.

(4) Choosing special content for students to present during the debrief: Embedded in the choice to trigonometric ratios, there was a variation of cognitive demand requiring the students to show a deeper understanding for the topic or higher-order thinking such as refuting a ratio. For example, Figure 9 shows that the teacher had chosen three questions for the students to present highlighting the embedded variation of cognitive demands: (i) after simplifying the surd, the student found that the triangle was isosceles; (ii) a student showed that two similar triangles sharing the same tangent ratio; (iii) a student showed that $cosx = \frac{3}{2}$ was impossible.

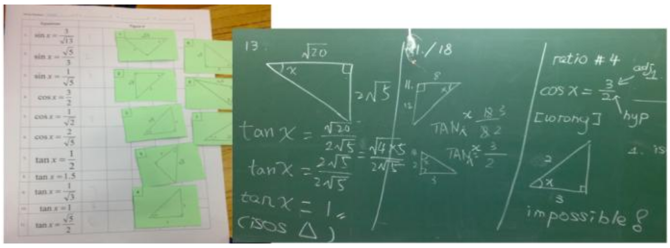


FIGURE 9: Highlights of students’ explanations in the debrief.

6.3 The Students' Perspectives

In the post-lesson interviews, most of the students gave positive feedback that they enjoyed the lessons, appreciated the collaborative approach and learned something further with the topic. The literal translation of their comments were shown in table 3, grouping into cognitive relating to the subject content; and non-cognitive relating to the collaborative setting and other aspects.

Cognitive (relating to the subject content)	Non-cognitive
• The content of the task is closely related to what is recently taught. The task acts as a revision tool and students can be able to cope with the related topics. • Students are reminded of the definition of the trigonometric ratios, especially "tan". • There are impossible trigonometric ratios. Learn to check the ratios carefully.	• Group mates can interact in a group. • It allows discussions, in which students feel more secure, particularly at the moment of facing to some difficulties. • No need to consult teacher immediately. Instead, group mates can be supportive to each other. • Remember some mistakes, which are reminded by the group mates. • A fun way to learn.

TABLE 3: The students' post-lesson feedback in the interview.

6.4 The Teachers' Growth

Participation in an intervention project such as the Rich Task Project inevitably posted a demand on the teachers' effort and time. Indicators that the project lessons were creating a better learning environment for students were important to teacher's motivation to carry on the project. In addition, the teacher's self-realization of professional growth was also very important. Many teachers expressed very positive sentiments towards the project, with much appreciation for their professional growth in the aspects of learning more about rich tasks, and 8 out of 9 said they saw their students improve performance during the lessons (Table 4).

	Professional growth	Teamwork	Student growth
Teacher 1	✔		✔
Teacher 2		✔	✔
Teacher 3			✔
Teacher 4			✔
Teacher 5	✔		✔
Teacher 6	✔	✔	
Teacher 7	✔		✔
Teacher 8			✔
Teacher 9			✔
Total	4 out of 9	2 out of 9	8 out of 9

TABLE 4: The teachers' comments in the post-project interviews.

6.5 Comparative Evaluation of The Research

For an implementation project, comparative evaluation is important and this can also be served as an indicator of success. Pirkko Vartianinen [66] proposed a frame for the examination of comparative evaluation. Examining implementation studies from the perspectives of comparative evaluation can be a goal-based evaluation. Thus, matching the results in the earlier sections, the characteristics can be summarized in table 5.

Principle	Selection of evaluation object	The level of comparative evaluation	The conceptual comprehension	The analysis of evaluation research
Outcome and goal attainment evaluation	Organization / program • School as a	The degree of goal attainment • The number	Established inputs, outputs and goals	Quantitative/ Causal/ Normative/ Summative

	unit • Teacher as a unit	of trials in the schools. • The level of student engagement.	• The ongoing sharing workshops provides a validity check of the research in real time via analysis of the UT-T and T-S artifacts.	• The evaluation instruments are qualitative/ normative. • The teacher post-project interview is a form of summative evaluation.

TABLE 5: A summary of the characteristics of outcome and goal attainment evaluations.

7. CONCLUDING REMARKS

The Rich Task Project was a project introducing pedagogical shift in traditional practice via the promotion of the use of rich tasks in Hong Kong, where the long established tradition sometimes inevitably raised the threshold for changes. The project celebrated its success with much endorsement from the participant teachers and the students. How did this happen?

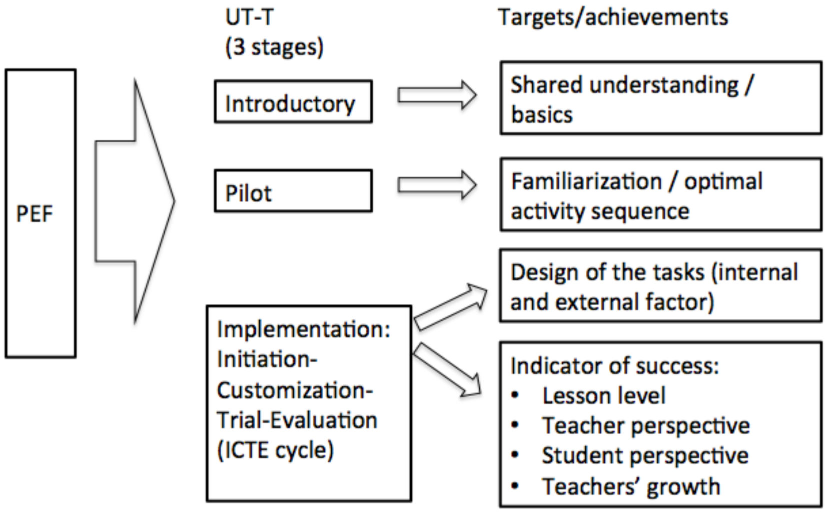


FIGURE 10: An overview of the analysis of the project via the lens of ergonomics.

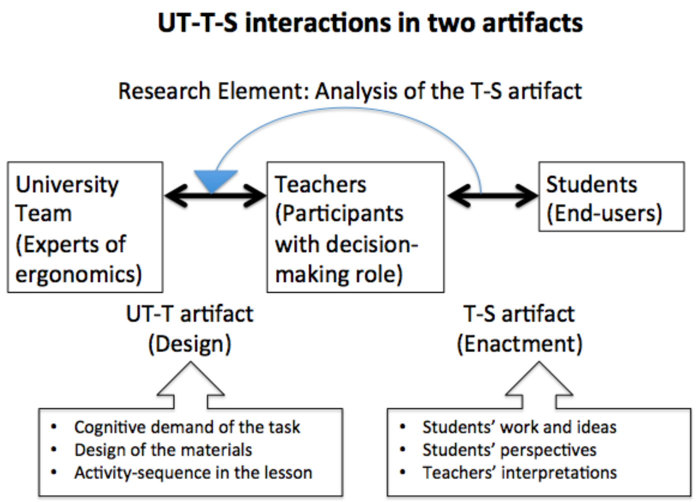


FIGURE 11: Curriculum Ergonomics for the Rich Task Project.

The paper presents an analysis of the project via the lens of curriculum ergonomics to give a nuanced interpretation of how the stakeholders interacted with the elements of the curriculum in the process of design and enactment. Figure 10 gives an overview of the analysis via the lens of ergonomics and Figure 11 shows the curriculum ergonomics for the Rich Task project. Conceptualizing curriculum ergonomics in a broader construct of human factors / ergonomics (HFE) and participatory ergonomics framework (PEF), curriculum ergonomics is the study of the interactions of the mix of participants (namely, the university research team UT, teacher T and students S) with the elements in the system, namely the interaction in UT-T and T-S artifacts. The former UT-T artifact is for the design of the rich tasks, whereas, the T-S artifacts is for the actual enactment of the rich tasks in the classrooms. In the design artifact, the interaction between UT (the specialist ergonomists) and the teachers (participants) covers:

- the cognitive demand of the task,
- the design of the materials,
- the activity sequence in the lesson,
- the feedback from the T-S artifact

For the enactment level, the teacher participants became the main decision-maker responsible for the interaction in the T-S artifact with another set of elements (student work and ideas, student perspectives and teachers' interpretations).

Impact of the study:
Who are the experts? The research has demonstrated to identify UT as ergonomics specialists and T as decision-making participants, as the methods of tapping the useful resources via the ongoing analysis of the UT-T and T-S artifacts as an effective way of implementation. Intertwining between the two artifacts, UT playing the role of specialist ergonomists added a research element for evaluating the success of the rich task lessons at the T-S artifact and providing feedback into the design artifact. Via the lens of ergonomics, some important elements become explicit, namely, the teachers' different agency roles in the interaction in UT-T and T-S artifacts, the student change in the T-S artifact, as well as how "integrating research into practice" [68] can be reified in curriculum ergonomics. This is very important accounting for the success of an intervention for the notion of professional agency referring to that the teachers have the power to act, to affect matters, to make decisions and choices are important to their identity and the reforms [69].

How to adapt resources (tasks) effectively? Concerning how to adapt a task and implement a lesson, there were two important shared operational outcomes, namely the idea-customization-trial-evaluation cycle and the optimal two-round-activities for scaffolding to engaging in tasks with a higher cognitive demand. The idea of customization is important for mathematics in the 21st century is moving beyond the basics and preparing students for the future digital society. During the adaption of resources and implementation, teachers are expected to orchestrate the class discussions, raising deepening questions and posing tasks that help students to reflect and build upon their current thinking [67]. The idea-customization-trial-evaluation cycle is supporting the teachers' growth in such direction.

Future direction of research:
Teachers' endorsing the achievement of the projects, expressing their appreciation of professional growth are mild evidence for the achievement. The new approach proposes an implementation of reforms from a research-integrated approaching while making use of the concept of expert ergonomists, participatory models with real-time comparative evaluation frames. It appears clear to us that there are a lot of potential of development for further studies of curriculum ergonomics in other cases for understanding the success and failure of curriculum interventions and changes, and we would like to propose the inclusion of curriculum ergonomics as a future agenda in for teacher education.

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