Chapter 8
Professional Development of Mathematics Teachers in Singapore

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Abstract Since the late 1990s professional development of all teachers, including mathematics teachers, in Singapore is guided and supported by the Ministry of Education and other professional bodies. With the adoption of the Professional Learning Communities (PLCs) framework teachers in schools belong to learning teams. They work and learn collaboratively at the school level through participation in a variety of professional development activities. From the narratives of three mathematics teachers about how they work and learn whilst working collaboratively at the school level it is apparent that mathematics teachers develop themselves through a number of ways, such as using resources like research papers and in-service courses to gain knowledge that helps them in resolving issues they face in teaching and learning mathematics. They may also participate in research projects and lesson study as part of PLCs in their respective schools. Teachers also engage in professional development activities to suit their individual needs. They attend higher degree courses at universities in Singapore and elsewhere. They also participate in professional development activities conducted regularly by the Association of Mathematics Educators, Singapore Mathematical Society and the Academy of Singapore Teachers.

Keywords Mathematics teachers · Professional development · Professional learning communities · Lesson study · Singapore

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8.1 Introduction

1997 marks the onset of systematic professional development for all teachers in Singapore schools. At the opening of the Seventh International Conference on Thinking on 2nd June, 1997 in Singapore, the then prime minister in his opening speech noted that:

> We must set up comprehensive mechanisms to continually retrain our workforce, and encourage every individual to engage in learning as a matter of necessity. Even the most well-educated worker will stagnate if he does not keep upgrading his skills and knowledge. Every organisation must first recognise the importance of the matter. It must require that its employees go through regular learning as a routine part of working life (Goh 1997).

Following the launch of the Thinking Schools Learning Nation (TSLN) initiative during the Thinking Conference, the Ministry of Education which is a Ministry of the government embarked on a systematic approach to induct teachers in lifelong learning, placing emphasis on continuous professional development so that schools keep abreast of advances in knowledge and learning both at the national and international fronts.

The second initiative, introduced in 2005, was the Teach Less, Learn More (TLLM) initiative (Ministry of Education 2005). TLLM builds on the groundwork laid in place by the systemic and structural improvements under TSLN, and the mindset changes encouraged in Singapore schools. It continues the TSLN journey to improve the quality of interaction between teachers and learners, so that learners are more engaged in learning and better achieve the desired outcomes of education. TLLM aims to touch the hearts and engage the minds of learners, to prepare them for life. It reaches into the core of education—why we teach, what we teach and how we teach. It is about shifting the focus from "quantity" to "quality" in Singapore's education. It emphasizes "more quality" in terms of classroom interaction, opportunities for expression, the learning of lifelong skills and the building of character through innovative and effective teaching approaches and strategies. It also emphasizes "less quantity" in terms of rote-learning, repetitive tests, and following prescribed answers and set formulae.

Systemic infrastructure has been put in place to support the TSLN and TLLM initiatives. Arising from these initiatives, several specific approaches have also been adopted by teachers to embark on their journeys toward excellence in instructional practices. In the following sections, we describe the systemic infrastructure that is prevailing for teachers in Singapore, how teachers work and learn collaboratively and also how teachers may develop themselves through professional activities and university courses at universities in Singapore and elsewhere.

8.2 Systemic Infrastructure

In support of TSLN vision, as of 1998, all teachers in Singapore are entitled to 100 h of training and core-upgrading courses each year to keep abreast with current knowledge and skills. The Professional Development (PD) is funded by the Ministry of Education. To support teachers in mapping their learning trajectories, in 2005 the MOE implemented an Enhanced Performance Management System (EPMS) (MOE undated). The EPMS is an appraisal system that contains rubrics pertaining to fields of excellence in the education system be it teaching, leadership or senior specialist. These rubrics delineate very clearly the competencies deemed necessary at each level and hence teachers are entrusted with responsibility of their own PD. The entitlement of 100 h of PD and EPMS as an appraisal system for teachers has created a significant buzz amongst them for learning opportunities.

For teachers to work collaboratively at the school level, in September 2005, in support of the TLLM initiative "white space" was introduced (Shanmugaratnam 2005). This is the time-tabled time for teachers during curriculum hours to meet, plan and deliberate on their instructional practices. To provide structure for teachers' collaborative work at the school level, in 2010, the Ministry of Education, unveiled the Professional Learning Communities (PLCs) framework (TDD 2010). This framework encourages the formation of Learning Teams in schools. These teams have the choice of adopting a range of collaborative methods/tools, such as Learning circles, Action research and Lesson study, to improve instructional practice through development in subject content knowledge and pedagogy.

In 2009, the Academy of Singapore Teachers (AST) was formed. The subject chapters at the academy are led by master teachers. The key objectives of the chapter are to (i) raise the professional standard in the learning and teaching of Mathematics, (ii) serve as a focal point for teacher collaboration and networking, and (iii) build a culture of professionalism and pride within the fraternity of Mathematics teachers.

8.3 Professional Development of Mathematics Teachers Through Working and Learning Collaboratively

As a consequence of three main developments, which are (i) the introduction of "white space" in 2005 (Shanmugaratnam 2005), (ii) the Ministry's adoption of Professional Learning Communities (PLCs) model as the preferred choice for collaborative learning in 2009 (Lee et al. 2013), and (iii) the PLCs framework (TDD 2010) that provided a structure for teachers to work collaboratively in 2010 teachers including mathematics teachers have been engaged in professional development by working and learning collaboratively. The framework of the PLCs focusses on three aims—improving student learning; building a culture of teacher collaboration; and addressing four critical aspects of outcomes couched in terms of

collective responsibility: What is it that we expect students to learn? How will we know when they have learned? How will we respond when they do not learn? How will we respond when they already know it?

The PLCs framework facilitates the formation of Learning Teams in schools. These teams have the choice of adopting a range of collaborative methods/tools, such as Learning circles, Action research and Lesson study, to improve instructional practice through development in subject content knowledge and pedagogy. In all schools, mathematics teachers belong to learning teams. They work and learn collaboratively at the school level through participation in a variety of professional development activities. We draw on three narratives of mathematics teachers to illustrate how teachers develop themselves professionally through participation in PLCs. The first narrative, shown in Fig. 8.1, is written by the head of mathematics department at school A. From Fig. 8.1, it is apparent that mathematics teachers in School A belong to teams, according to the grade levels they teach. Their student outcomes guide them in sourcing for areas of concern they would like to address collectively. They appear to work systematically and collaboratively for a period of time, drawing on resources such as readings (research papers, books, on-line materials, etc.) and in-service courses to enlarge their knowledge and pedagogical skills so as to improve the teaching and learning of mathematics through meaningful activities such as purposeful homework and effective questioning.

The second narrative, shown in Fig. 8.2 (Example 2), is written by a lead mathematics teacher in School B. A lead teacher is one who has demonstrated a high level of competence in both mathematical content and pedagogical content knowledge. In addition to their teaching duties they are also responsible for the development of mathematics teachers in their respective schools and other dedicated schools. From Fig. 8.2, it is apparent that a group of mathematics teachers in School B work and learn collaboratively as a PLC through participation in a research project. The project is funded by the Academies Fund of the Ministry of Education and led by professors at the National Institute of Education, Singapore. The lead teacher who wrote the narrative, is also actively involved in the conceptualization and implementation of the project. It is evident from the narrative that such projects reflect a gradual shift in the centre of gravity away from the University-based, "supply-side", "off-line" forms of knowledge production conducted by university scholars for teachers towards an emergent school-based, demand-side, online, in situ forms of knowledge production conducted by teachers with support from university scholars. Teachers participate, in the project, as a team of four or more from a school. This allows teachers to work collaboratively at the school level to integrate their new knowledge acquired whilst participation in the project into their classroom practice. It is understandable why teachers participate in the project as its goal is in line with improving student teaching and learning which is at the heart of PLCs. Whilst the project facilitates the acquisition of new knowledge and integration of the knowledge into classroom practice, it also facilitates their participation in two PLCs, one at their respective school level and another at the project level.

As part of the PLCs, in my school [School A] mathematics teachers belong to teams according to the grade levels they are teaching, for example grades 7-8 or grades 9-10. I belong to the grades 7-8 team and there are five of us in the team. Each year we examine the student outcomes at the end of the academic year and list two areas that we would like to focus on in the coming year. For example in Nov 2014, the two areas we identified were: effective questioning and meaningful homework. We planned to work on each of the two areas for half of the year 2015.

For the first half of the year we focused on meaningful homework. We drafted our plan for the weekly meetings. First we sourced for readings. All of us read the readings that we could source for homework. After reading and discussing the readings for three weeks, we tried to clarify "what is meaningful homework". After much discussion, we defined it to be homework that would:

- engage our students in consolidating their learning during mathematics lessons (developing skills, revisiting properties, using the concepts and reinforcing the representations),
- experience national examination types of questions, and
- solve non-routine mathematical tasks.

We also tried to work out the proportion of each type of tasks that were appropriate for one homework assignment and the duration of each homework assignment. Finally, we took our homework assignments that we were giving our students and examined them in light of what we had discussed and defined. The exercise led to a significant awareness of how we blindly assigned homework, which at time was only to hone procedural fluency of skills. The team gained much from their shared investigation and certainly worked and learned collaboratively.

In the second half of the year we took a slightly different approach and all five of us enrolled for an in-service course conducted by Prof Berinderjeet Kaur on Effective questioning and facilitation techniques for secondary mathematics teachers at the National Institute of Education, Singapore. After attending the 4 sessions of 3 hours each during out of school hours, we resumed our discussion of how we could integrate our learning into our classroom practice during our PLC meeting times. During these meetings we took turns to plan a hypothetical lesson and focused on what questions we would ask as the lesson unfolded, so that the questions were effective in "getting students to articulate their thought processes". Once again we worked and learned collaboratively. The exercise led us to be aware of how we can move students' thinking up the rungs of the cognitive ladder, from merely asking them to recall to justifying their responses.

Fig. 8.1 Example 1—Activities of a PLC of mathematics teachers in School A

Since the setting up of the Centre for Research in Pedagogy and Practice (CRPP), in 2002, at the National Institute of Education, Singapore projects similar to the one described in example 2 have had a significant impact on the professional development of teachers. Two such past projects are the Enhancing the Pedagogy of Mathematics Teachers (Teaching for Reasoning and Communication) (EPMT-RC) project (Kaur 2009, 2011) and the Think-Things-Through (T^3) project (Yeap and Ho 2009). The aims of the EPMT-RC were three fold: to equip teachers with knowledge about mathematics lessons that facilitate reasoning and communication, support teachers in integrating their new knowledge into classroom practice and contribute towards the development of fellow teachers. The project involved both primary schools and secondary schools mathematics teachers. The deliverables of this project, namely resources crafted by teachers (Kaur and Yeap 2009a, b; Yeap

In my school [School B], the mathematics teachers work and learn collaboratively through Professional Learning Communities (PLCs), level meetings and participation in research projects with NIE professors. One current research project is the Enhanced Pedagogy of Mathematics Teachers (Teaching for Metacognition) with Professor Berinderjeet Kaur and Toh Tin Lam from the National Institute in Singapore.

We work and learn collaboratively in the current project we are participating in. This year, 2015, the mathematics teachers in my school, together with teachers from six other schools in the N6 cluster, came together every Monday, for 6 weeks, to focus on how metacognitive strategies can be infused in the teaching and learning of mathematics, and how a metacognitive culture can be developed in our mathematics classrooms. Teachers were engaged in professional development as they learnt how to craft knowledge building tasks from typical performative tasks found in textbooks and to infuse 10 suggested metacognitive strategies in their lessons, so as to facilitate explicit articulation of students' thinking and encourage students' construction of mathematical knowledge both independently and collaboratively. The tasks crafted were shared with everyone for critique and further refinement.

Teachers were also introduced the concept of Teacher Noticing and were encouraged to video-record their lessons that they later, as a team, reviewed and reflected upon through four lenses – teaching, learning, task and participation. One of my lessons was recorded and viewed by the teachers who in turn gave constructive feedback on how I could further improve my lesson. In addition, teachers learnt a novel tool – lesson play, to write a lesson or part of a lesson in the form of a script for dialogue, featuring imagined interactions between the teacher and students. In the process of writing their lesson plays, teachers' pedagogical and subject matter knowledge were enhanced as they came together to discuss on the mathematical and pedagogical dimensions of teaching, focusing on aspects of practice such as teaching moves and classroom discourse. The teachers' thinking was made visible in the process. Besides crafting knowledge-building tasks and adopting metacognitive strategies to engage students in their learning, teachers also learnt to shape their classroom discourse and interactions by establishing mathematical and socio-mathematical norms that teachers discussed and collectively agreed upon.

Finally the teachers in each of the seven schools worked together to plan and enact lessons designed using the knowledge they had acquired thus far, with the goal of developing metacognitive skills amongst our students. These lessons were video-recorded and showcased in a meeting of all seven schools, presenting segments of the lessons that showed teachers developing metacognition using one or more of the metacognitive strategies identified. Again, peer feedback was sought from the audience who viewed through the four lenses of teaching, learning, task and participation. With the consolidated peer feedback, teachers in each school got together, with guidance from the researchers, reviewed the enactment of their planned lesson. During the review, they wrote a narrative of the lesson highlighting segments of lessons where metacognitive strategies that were evident and also missed opportunities. Teachers were also encouraged to write a journal about their learning of the process of planning, enactment and review. Teachers' learning was the richest at this stage as they learnt that a good lesson comprised careful planning as well as enactment. After addressing the gaps in the enacted lesson, teachers once again worked collaboratively to plan for another mathematics lesson for enactment, bearing the lessons they had learnt in mind.

Fig. 8.2 Example 2—PLC of mathematics teachers in School B

and Kaur 2010) have contributed to several school-based professional activities that have had positive impact on classroom practice of many teachers in Singapore.

The T^3 project investigated teacher change when teachers learnt from each other in a professional community, i.e. knowledge–in–practice (Cochran-Smith and Lytle 1999). The project involved primary school mathematics teachers. The teachers were given a set of word problems to use in their lessons. They were also provided with lesson notes to support their use of the word problems such that students

Mini sausages are sold in packs of 6. Buns are sold in bags of 8. We do not want to have either the sausages or buns leftover.	
Part 1 We use a mini sausage with a bun to make a hotdog. What is the fewest number of packs of sausages and buns we should buy?	Part 2 We use 2 mini sausages with a bun to make a hotdog. What is the fewest number of packs of sausages and buns we should buy?
Part 3 We use 3 mini sausages with a bun to make a hotdog. What is the fewest number of packs of sausages and buns we should buy?	Part 4 We use 1, 2 or 3 mini sausages with a bun to make a hotdog. What is the fewest number of packs of sausages and buns we should buy?

Fig. 8.3 Word problem from T^3 project (Yeap and Ho 2009, p. 138)

considered the contexts of the problems when solving them. They were encouraged to use the word problems provided by the project in their lessons, and create more word problems for use in their lessons. In their professional learning communities they were also encouraged to discuss with colleagues, about the problems and how to use them in their lessons. No structured training was provided to support their learning. Figure 8.3, shows an example of word problem provided by the project for teachers to work on. The three-year long project engaged teachers in professional development while researching their levels of change, i.e. were the teachers merely ignoring, imitating, integrating or internalizing learning afforded by the project.

There are also projects at cluster levels, initiated by school leaders, which involve several schools with groups of mathematics teachers at the school level working and learning collaboratively. One such project was the Assessment Literacy project of the North 2 cluster comprising 15 schools (Chua 2014). This assessment literacy project involved teachers from the 15 schools coming together as a group to acquire knowledge about good assessment practices for mathematics from an expert, groups of teachers from the respective schools (i.e. the PLCs at the school level) selecting one practice and implementing it across a grade level for an academic school year and examining the feasibility of the chosen practice and its impact on student learning. During the implementation year, teachers worked collaboratively in their respective PLCs in schools. They also met with the expert periodically to seek guidance and clarify their knowledge about the mode of assessment they were investigating. The project culminated with the PLCs at the schools coming together during a conference that was organized by the school leaders to showcase their learning through workshops that they conducted for fellow teachers at the national level.

The third narrative, shown in Fig. 8.4 (Example 3), is written by a mathematics teacher in School C. The teacher has been teaching mathematics for the past 7 years to students. From narrative three, in example 4, it is apparent that lesson study is one of the tools teachers adopt for developing themselves whilst working and learning collaboratively in PLCs. Lesson Study first came to the attention of

In my school [School C], the mathematics teachers work and learn collaboratively through Professional Learning Communities (PLCs). The PLCs are free to decide what ever tool they wish to utilise for their development. I belong to a Lesson study group. One of the teachers (expert) in my PLC has worked very closely with Professor Christine Lee from the National Institute of Education, Singapore. Prof Lee is a pioneer for Lesson Study in Singapore. For the school year, 2015 my PLC was engaged in a Lesson Study. The revised school curriculum of 2012 places heightened emphasis on learning experiences for the construction of mathematical knowledge by learners. The topic we adopted for our lesson study was three dimensional geometry – angles between lines and planes. The expert teacher in our group of 5 guided us as we worked through the lesson study cycle over a period of six months. We invited a master teacher of mathematics from the Academy of Singapore teachers and a professor from the National Institute of Education to be part of the resource panel for the demonstration lesson. The post-lesson critique by teachers and the invited quests contributed towards deepening of our knowledge of spatial visualisation and sequencing of activities to aid student's constructing of spatial concepts.

Fig. 8.4 Example 3—PLC of mathematics teachers in School C

educators in Singapore in 2004, during a conference on Cooperative Learning held in Singapore when researchers from the University of Tokyo and Lewis from Mills college shared with participants how Lesson Study was being used in Japan to develop a collaborative culture amongst teachers engaged in professional development of teachers (Lee and Lim-Ratnam 2014). Adoption of lesson study from Japan by educators in Singapore began around the year 2005 (Fan et al. 2009; Lim et al. 2011). In a research project, believed to be the first on Lesson study in Singapore, conducted by Fan et al. (2009) from 2006–2007, it was found that through the actions of planning, teaching, reflecting, and revising, teacher participants deepened their knowledge and skills which resulted from the diverse community that worked together in the study. It was also found to be a good means of mentoring the beginning teachers by senior teachers in a school. Some examples of school-based Lesson Studies involving mathematics teachers, that have been published, are "Division with remainder: lesson study to promote conceptual understanding" (Fang et al. 2012); "Area of rectangles" and "Equivalent fractions" (Fan et al. 2009).

From the three narratives, we are unable to draw any issues that the teachers face whilst participating in PLCs and also developing themselves. Research by Hairon and Dimmock (2012) about PLCs taking root in schools identified three potential difficulties when PLCs were implemented in schools in Singapore. They were high teacher workloads, ambiguity of PLC processes and their efficacy, and hierarchical system and workplaces.

Lee and Lim-Ratnam (2014) also noted that the

> the implementation of lesson study in Singapore has much support in terms of form and structures, but is lacking in the spirit and substance of *jugyu kenkyuu**. The main difference that we perceive between Singapore lesson study and Japanese lesson study is that in Singapore our focus tends to be on student learning gains rather than making connections with the long-term goals of the school or the national curriculum (p. 58).

**jugyu kenkyuu* is the Japanese word for Lesson Study

8.4 Professional Development Activities to Suit Individual Needs

The EPMS entrusts teachers with the responsibility of developing in their fields of work, specifically teaching in this case. Teachers are guided by their mentors in school and self to pursue professional activities that address their needs. For teachers who wish to pursue further professional qualifications, they may enrol for higher degree courses at universities in Singapore and elsewhere. In Singapore, at the National Institute of Education which is an Institute of the Nanyang Technological University these courses lead to master degrees in Education (Mathematics), Science (Mathematics Educators), Art and Philosophy; and also Doctorates in Philosophy and Education. Others may choose to enrol for relevant short in-service courses, workshops, seminars and institutes. These professional learning activities are conducted by university academics, master teachers and senior teachers.

Professional bodies such as the Association of Mathematics Educators (AME), Singapore Mathematical Society (SMS) and the Academy of Singapore Teachers (AST) are active in providing professional development and learning activities for mathematics teachers on a regular basis. Since 2005, the Association of Mathematics Educators holds an annual conference for mathematics teachers. The conference is thematic and supports the trust of the school mathematics curriculum, as shown in Fig. 8.5, as well as initiatives of the Ministry of Education such as 21st century competencies (Ministry of Education 2010). It is held on the first Thursday of the 4 week long school break in June each year. The date of the conference does not conflict with teachers school work as the first week of the 4 week break is dedicated to the development of teachers. The themes of the past 11 conferences are shown in Table 8.1.

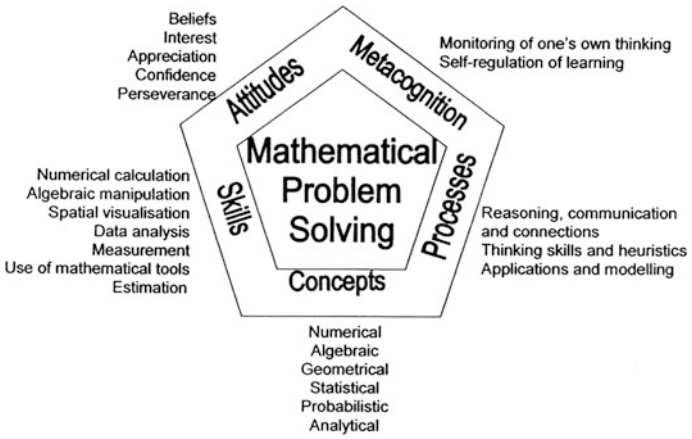

Fig. 8.5 Framework of the Singapore school mathematics curriculum (Ministry of Education 2012)

Table 8.1 Year and theme of AME Mathematics Teacher Conferences in Singapore

Year	Theme of Conference
2005	Assessment
2006	Enhancing mathematical reasoning
2007	Mathematical literacy
2008	Mathematical problem solving
2009	Mathematical applications and modelling
2011	Communication, reasoning and connections
2012	Nurturing reflective learners
2013	Learning experiences in mathematics
2014	Assessment in mathematics
2015	Developing twenty-first century competencies in the mathematics classroom
2016	Empowering mathematics learners

Since 2008, the Association of Mathematics Educators has also published a yearbook that specifically provides for the needs of teachers. Again the yearbook is thematic, as it draws on contributions of scholars to the conferences. It comprises chapters written by renowned mathematics educators from Singapore and the world that are grounded in theory but laden with classroom vignettes and mathematical tasks for teachers to glean knowledge from for their use in classrooms. The titles of the yearbooks published so far are: Mathematical Problem Solving (Kaur et al. 2009), Mathematical Applications and Modelling (Kaur and Dindyal 2010), Assessment in the Mathematics Classroom (Kaur and Wong 2011), Reasoning, Communication and Reasoning in Mathematics (Kaur and Toh 2012), Nurturing Reflective Learners in Mathematics (Kaur 2013), Learning Experiences to Promote Mathematics Learning (Toh et al. 2014), Effective Mathematics Lessons through an Eclectic Singapore Approach (Wong 2015), and Developing 21st Century Competencies in the Mathematics Classroom (Toh and Kaur 2016).

The book Nurturing Reflective Leaners in Mathematics was reviewed by Annie Selden for the Mathematical Association of America (MAA 2013). Selden noted that the subject of the book was metacognition because it is one of five components of the Singapore school mathematics curriculum framework for problem solving and one of the framework's principles for mathematics teaching stated that "teaching should build on students' knowledge, take cognizance of students' interests and experiences; and engage them in active and reflective learning" (Ministry of Education 2012, p. 21). The review highlights that reflective thinking about mathematics does not come naturally to most students, that teachers need well designed tasks that promote reflection, and there needs to be "good teaching and deliberate talk to promote reflection that brings new, higher level perspectives" (Kaur 2013, p. 156). In addition, it states that the book has for school teachers at all levels some ideas of tasks that can be used to induce reflection in students' mathematical thinking. The review by Selden for the Mathematical Association of America affirms the intent of the thematic yearbooks of the Association of Mathematics Education in Singapore.

8.5 Conclusion

It is apparent that since the late 1990s, the Ministry of Education, led by a Minister from the government with a budget that ranks amongst the top three items of the Gross National Product of the country, has guided and provided substantially for the professional development of all teachers in Singapore. Therefore, professional development is an essential component of teachers' lifelong endeavour. Other agencies, professional bodies like the Association of Mathematics Teachers and the Singapore Mathematical Society, too have played a significant role in professionally developing mathematics teachers in Singapore. The sustained support and opportunities for development of teachers, including mathematics teachers, have in the last two decades or so created a culture of lifelong learning at the individual, school and national levels. Therefore, it may be said that no teacher is left behind in developing him or herself. Due to the multitude of opportunities available for mathematics teachers to develop themselves, a lot depends on individuals to set their personal ceiling levels.

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