THE EFFECT OF ITERATIONS, COLLABORATION, AND DESIGNING GEOGEBRA MODULES ON IN-SERVICE SECONDARY MATHEMATICS TEACHERS

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Abstract: The ability to design technological activities or applets is one of the new challenges for teachers in the context of digital learning. Technology teacher training should convert from presenting solutions for teachers, to assist them to become better designers in resolving their own problems. To be able to do that this study used design-based research methodology and worked collaboratively and iteratively, through three iterations with the use of the powerful open-source software GeoGebra. Three theories were used in this study to contribute to our goals: 1) Technological Pedagogical Content Knowledge (TPACK); 2) the Diffusion of Innovation Theory; and 3) the Zone Theory. The study is based on a qualitative multiple case study design with four in-service secondary mathematics teachers (three females and one male) with diverse backgrounds. Analysis of the data indicated improvements of participants in their utilization of GeoGebra in their practices as well as in their TPACK integration levels. Unlike the fast improvement in participants' TPACK, the change in practices was slow, but considered sustained. In addition, effects of collaboration and iterations with researchers decreased hinderances in GeoGebra integration and improved some of the assistance factors. With this study we aim to contribute to both theory and practices for teacher professional development.

Keywords: Technology adaption, professional development, GeoGebra, DBR, TPACK

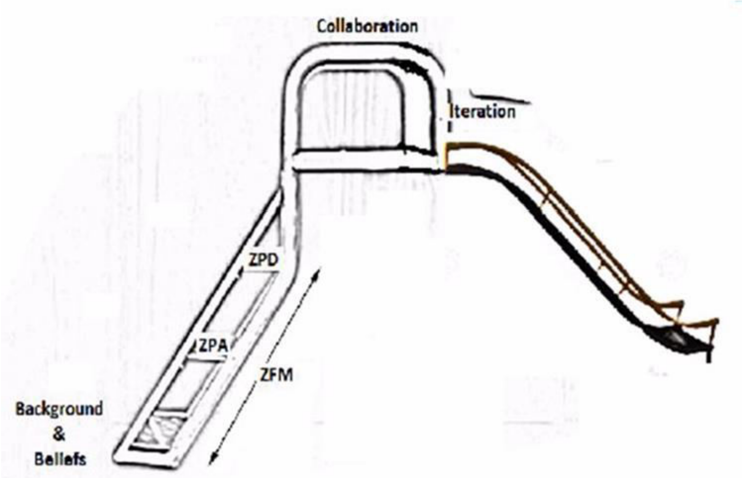
1. Introduction

In order for teachers to change their practices they need more than just participating in professional development workshops. Among others they also need scaffolding, iterations, and collaboration. Regularly, after attending such workshops in general and technology related workshops in particular with any duration, teachers learn numerous new teaching-related techniques and sometimes they take the decision to change their practices to apply what they have learned. However, then they face ample difficulties holding them back from effectively integrating technologies into their own teaching. We believe when teachers climb the technology adoption ladder in small steps and hold on to its rails (Collaboration), teachers will more likely continue climbing up and less likely to slide back down to their initial state, this idea is demonstrated in Figure 1.

Teachers' willingness to integrate technology in their classes and continuation in using them depends greatly on their successes with utilizing technologies (**Ertmer & Ottenbreit, 2009**). These successful experiences require teachers to be able to actively participate in the process of technology integration (**Voogt et al., 2011**). This study aspires to extend previous studies explored the impact of professional development on integrating technologies, in particular GeoGebra in our case, in teaching mathematics in three directions: the type of professional development, the unit of analysis, and the research design and methodology. For the professional development the delivery mechanism this study used including iterations of training, follow-up, and re-training in a collaborative and reflective way. In terms of the unit of analysis, this study was concerned with teachers' change over three iterations: 1) whether or not teachers used what they learned from the workshop in their teaching; 2) the change in their practices, specifically in using inquiry-based activities; and 3) their change in TPACK levels, specifically their ability to design *GeoGebra*-based activities.

The research design used was in depth multiple case study of in-service secondary mathematics teachers and the methodology used was design-based research. In addition, the choice of the technology software GeoGebra was because of its widespread usage by teachers and the availability of millions of free-to-use resources. In what follows a summary of previous related studies done on GeoGebra and a brief introduction on the theories used in this research.

Figure. 1 The ladder and slide framework (Kasti, 2018)



2.Significance of the study

Since this study aims to address multiple aspects of the technology integration problem, the results of this study may lead to a more effective and sustained model of technology integration in mathematics classrooms. The outcomes of this research have implications for both theory (design principles) and practice. Decision-makers on a small scale (school) or large scale (country) can use the theory-based instruments that were developed for the purpose of this study to determine the inhibitors and facilitators of technology integration in classrooms. Moreover, the process of iterations to be used in answering the research questions is as important as the outcome. The close work of the researcher with practitioners within the context of a solid theoretical background can be replicated not only with mathematics teachers but also for any other subject. In terms of the impact on practice, the *GeoGebra* modules that were developed, implemented and re-developed could provide a booklet for secondary mathematics teachers to use in their teaching as well as universities in their practicum courses. The whole process, including the modules, could be replicated and adapted for other curricula as well. In terms of design principles, some professional development principles on how to effectively change in-service teachers' practices could emerge.

3.Review of Related Studies

Numerous studies have already looked at the impact of *GeoGebra* professional development on teachers' practices such as (**Escuder & Peitgen, 2011; Lavicza et al., 2010; Preiner, 2008; Tatar et al., 2016**).Based on the results of their studies, researchers have also provided recommendations in terms of *GeoGebra* professional development. For instance, **Preiner (2008)** emphasized the importance of: being flexible in order to respond to all of participants' needs, accounting for teachers' various levels of mathematical knowledge, anticipating technical difficulties or malfunctions, integrating a variety of teaching methods such as hands-on and discussion-based activities, and limiting the amount of mathematical content to be covered so as not to overwhelm the participants. The teachers in **Lavicza et al.'s (2010)** study indicated that professional development should focus more on pedagogical approaches so that they can learn how to implement it in lessons. Their study also highlighted the importance of researcher-teacher and teacher-teacher collaboration. Others have recommended that workshops aim at convincing participants of the usefulness of *GeoGebra* and addressing teacher resistance for the use of technology **(Tatar et al., 2016)**. The positive outcomes demonstrated in **Escuder and Peitgen's (2011)** study further suggest that professional development on *GeoGebra* should be sustained and long-term and should focus on the combination of curriculum, instruction and technology. It should also model effective teaching practices and create a collaborative and learner-centered environment **(Escuder & Peitgen, 2011)**.**Misfeldt y Zacho's (2016)** study demonstrated the importance of collaboration among groups of teachers in designing and implementing instructional materials using *GeoGebra.*

This study took into account most of these previous recommendations, we worked collaboratively and iteratively with teachers. The choice of activities was flexible, each teacher chose the activity needed for their chosen lesson required from their curriculum. So, no experimental-out of context-intervention was applied.

On the other hand, there were another set of previous studies mentioned the lack of theoretical and conceptual frameworks to inform and guide research related to technology adoption by teachers as one face of the problem **(Angeli & Valanides, 2009; Drijvers et al., 2010; Haspekian, 2014; Mishra & Koehler, 2006; Pepin, Gueudet & Trouche, 2013; Ruthven, 2007; Voogt, Knezek, Cox, Knezek, & ten Brummelhuis, 2011)**. That is why in this study we have used three theories and the concept of networking theories to fill that gap.

4.Objectives of The Study

The objectives of this study are:

- To study the effect of iterations and collaborations on the level of in-service secondary mathematics teachers GeoGebra integration level.
- To study the possible way(s) to help teachers become technology designers.

5. Theories used in the study

Three specific theoretical frameworks relating to technology integration laid the groundwork on which this study was based. These theories were: technological pedagogical content knowledge (TPACK), Zone Theory, and innovation diffusion theory (IDT). In addition, the notion of networking theories **(Bikner-Ahsbahs, 2009; Prediger et al., 2008)** was used because it "provides a good starting point that might help in better understanding the role of digital technology in mathematics education and, as a consequence, to contribute to the learning and teaching of the topic" **(Drijvers, 2012, p. 14)**. More specifically the strategies of "combining and coordinating" the well-fitting elements from these three theories were used**(Prediger et al., 2008)**. Each of these theories will be briefed in turn.

5.1 TPACK

Building on the work of **Shulman's (1986)** pedagogical content knowledge (PCK), Koehler and Mishra developed technological pedagogical content knowledge (TPACK), previously known as TPCK. **Koehler & Mishra (2008)** defined TPACK as:

> …the understanding that emerges from an interaction of content, pedagogy, and technology knowledge…TPCK is the basis of effective teaching with technology. It requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problem that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones. (p. 17)

In order to effectively integrate technology in a specific context, teachers not only need to develop knowledge in each of these key domains (technology, pedagogy, and content), but also to interrelate among them**(Koehler & Mishra, 2008)**. In addition, the role of context (i.e., subject matter, grade level, student backgrounds, etc.) is an essential and overarching component of the TPACK framework **(Mishra & Koehler, 2006)**.

While TPACK provides one aspect of the factors that impact teachers' technology integration, it is not comprehensive enough because it does not take account what factors (hindering or assisting factors) teachers face when they want to apply their knowledge and skills in their teaching. We believe that change of practices does not depend solely on knowledge but on many other factors and that is why we have to look at all facets into account. That is why the Zone Theory was also used.

5.2 Zone Theory

This theory was developed by **Valsiner (1997)** who extended **Vygotsky's (1978)** Zone of Proximal Development (ZPD). Applying Zone Theory to the context of technology, there are three categories of factors affecting technology integration by teachers: zone of proximal development (ZPD), zone of free movement (ZFM) and zone of promoted action (ZPA) **(Goos et al., 2010)**. ZPD is defined as the potential technology ability that teachers can reach with the support of more experienced individuals. ZFM refers to contextual, environmental or systemic constraints that limit teachers' technology integration. ZPA refers to the training experiences that teachers received as part of their pre-service education or in-service professional development on the integration of technology. In order to integrate technology in their classes, teachers who are novice in using technology should have their zone of promoted action (ZPA) be within their zone of free movement (ZFM) and consistent with their zone of proximal development (ZPD) **(Goos, 2005).**

Finally, while the TPACK and Zone Theory frameworks provide a holistic view of the individual and contextual factors that impact teachers' technology integration, they do not elucidate the processor stages that teachers go through as they learn about a new technology. But if we take account of that then we will have better three-dimensional view (The three theories together) of integrating technology by teachers in their classrooms and the models will be improved. It is for this reason that **Rogers' (1995, 2003)** innovation diffusion theory (IDT) was chosen.

5.3 Diffusion of Innovation Theory

As defined by **Rogers (2011)**, “diffusionis the process by which an innovation is communicated through certain channels over time among the members of a social system” (p. 37). According to **Rogers (1995, 2003)**, individuals progress through five different stages of innovation adoption and diffusion: 1) knowing about the innovation, 2) forming an attitude toward the innovation, 3) adopting or rejecting it, 4) implementing the innovation, and 5) confirming this decision.

Rogers (2011) argues that there are five groups of variables or factors that increase the rate of adoption of an innovation (Figure 2).

Figure. 2 Edited version of the Innovation theory stages

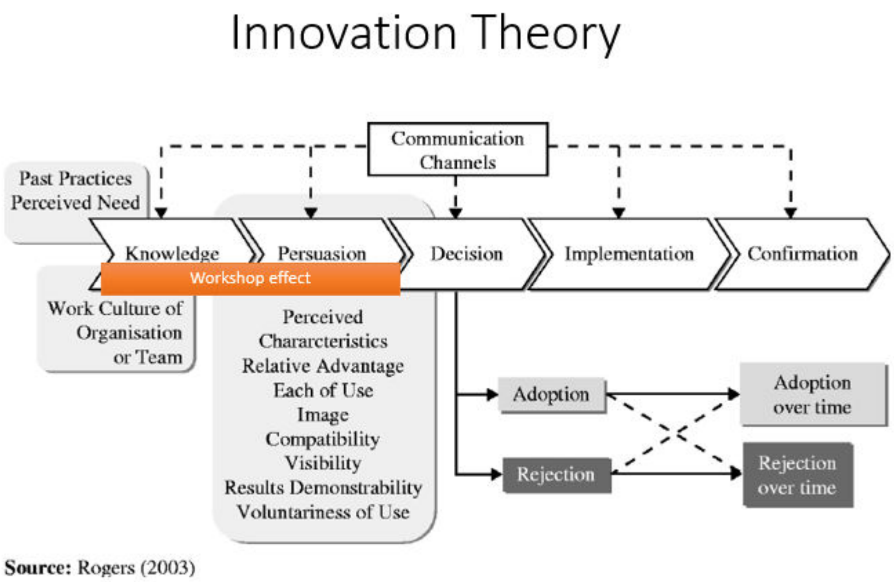


Figure 2. was edited to show that most professional development workshops, regardless of their duration, rarely have an effect more than the “persuasion phase” sometimes it extends to the “decision phase” where teachers decide to integrate technology in their classrooms. However, when faced with any limiting factor(s) that belongs to any of the three zones teachers surrender to the easiest escape or slide back to the rejection phase.

Taking all of the above into consideration, and since we are looking at teachers and professional development from many theoretical perspectives, then we need a suitable methodology. We need to work closely with teachers in collaborative and iterative manner in order to get over most of the zones limiting factors. For that end, we have selected in this study the Design-Based Research (DBR) as a suitable and powerful methodology. In the following sections, a briefing of the methodology, participants selection, instruments used and data analysis. For more details refer to **Kasti (2018).**

6. Methodology

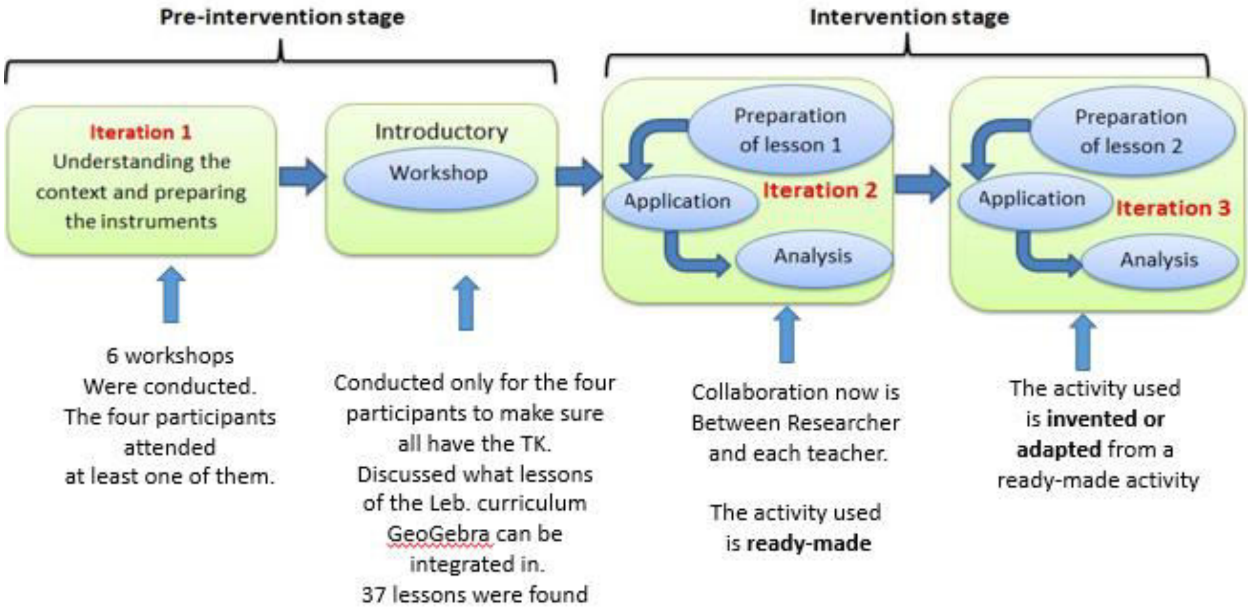
There are many methodologies that can fit the aims of this research, but we chose DBR because it has the following five basic characteristics. The DBR is: 1) pragmatic; 2) grounded in theory and practice; 3) interactive, iterative, and flexible; 4) integrative; and 5) contextual **(Wang & Hannafin, 2005)**. In addition, as **Wang & Hannafin (2005)** defined design-based research:

> …a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories. (p. 6)

And this is exactly what we need. We are aiming to design better and more effective professional development principles in addition to trying to networking the three mentioned theories.

DBR is appropriate because it mandates close work with practitioners within a real context and on theoretically-based grounds. Following DBR methodology the study was made over two stages: the pre-intervention and the intervention phase. The intervention phase was done over two iterations. Figure 3 explains the activities done in those phases and iterations.

Figure. 3 The study phases and iterations



6.1 Participants

The participants were four in-service secondary mathematics teachers. They teach the Lebanese curriculum in English. They were selected in one of the workshops given by the researcher. The selection criteria were on two bases: extent at which GeoGebra was used in their teaching and the barriers they have faced. Table 1 Summarizes their main demographic characteristics.

Table. 1 Participant Demographics, Practice and Zones Level regarding the use of GeoGebra in their teaching

Name	Age	Highest degree	Teaching experience	Practice level	ZFM	ZPA	ZPD
Amani	50-55	BS	25 years	Low	Moderate	Moderate	Low
Tima	23-26	Masters	2 years	Moderate	Low	Moderateee	N/A*
Sara	33-40	BS	7 years	Moderate	Moderate	Low	N/A
Hazem	41-50	Masters	31 years	High	Moderate	N/A	N/A

**Note*. N/A = The zone was not considered a barrier to *GeoGebra* integration
Practice level means how much the participant use GeoGebra in this/her teaching

6.2 The instruments

This study was implemented in two phases: pre-intervention and intervention, with each phase having its own set of parallel instruments. All of the instruments were adapted by the researcher from previously tested instruments and based on multiple well-known theories. In addition, they were all administered on an individual basis with each participant in his/her school and were tape-recorded after participants' approval.

Pre-intervention phase instruments

- Demographics
- Instructional practices in *GeoGebra* questionnaire (IPGQ; Form 1) prepared by the researcher
- Barriers in using technology questionnaire (BUTQ; Form 1) prepared by the researcher based on the zone theory.
- TPACK development level questionnaire (TPCKLQ; Form 1) adapted from **Niess et.al (2009)**

Intervention Phase Instruments

- Lesson selection and preparation semi-structured interview (LSPI) adapted from **Angeli & Valanides (2009) and Harris et al. (2012)**
- Lesson assessment criteria semi-structured interview (LACI) adapted from **Harris et al. (2012)**

- Instructional practices in *GeoGebra* semi-structured interview (IPGI; Form 2).
- TPACK development level semi-structured interview (TPCKLI; Form 2).

The difference between Form1 and Form2 instruments is that Form 2 included a list of factors that came in the way of the teachers when integrating GeoGebra in their lessons. These factors (listed in the BUTQ; Form 1) could have assisted or hindered teachers from integrating technology in their practices and TPACK.
All instruments and GeoGebra activities were piloted in the pre-intervention phase. Data collected from the instruments were analysed using SPSS and it was found that the reliability is more than 0.9 using Cronbach alpha for each of the instruments. After that stage the qualitative part of the study was ready to be conducted aiming at studying the effect of collaboration and iterations on in-service secondary mathematics teachers' TPACK, practices and zones. Moreover, as mentioned before, the first iteration was made with ready-made GeoGebra activities. Those activities were also piloted.

6.3 The GeoGebra activities

In the first iteration teachers were given ready-made GeoGebra activities and they were asked to select from them according to their own scope and sequence in their own schools. Those ready-made activities were designed applied and improved in the classes the researcher was teaching. Most activities were designed to improve the TPACK of mathematics teachers. Each activity covered some aspects of the software (technological knowledge) and its context was a specific mathematics concept (content knowledge). In addition, the activity could be applied in a computer lab and designed in a way that the student alone or with the teacher help can discover the result (pedagogical knowledge). In this study, based on the three theories mentioned earlier, we assumed that you cannot immediately ask a teacher to be a designer and hence it is better to do that in small steps and over some iterations with the availability of professional scaffolding. Doing that will increase teachers' self-esteem and decrease the effect of the limiting factors belonging to any of the three zones.

6.4 Data analysis

Since this is a qualitative study, each item in every instrument was considered as a unit; that is, the same item was compared before and after the intervention for each participating teacher. In addition, descriptive measures were calculated to specify the level in each of the parts: practices level, TPACK, and zone levels.
For the practice part, teachers were asked about how often do they use GeoGebra in their teaching-learning process, how did they use it (as presenting or discovery lesson), and where did they use it (in class, computer lab…). For all the items there were three levels: never, sometimes or most of the time.
For the TPACK, the instrument was adapted from **Niess et.al (2009)** instrument (Using GeoGbera instead of technology). The TPACK five levels were:

1. *Recognizing* (knowledge), in which teachers are able to use the technology and recognize the alignment of the technology with mathematics content, yet, do not integrate the technology in the teaching and learning of mathematics.
2. *Accepting* (persuasion), in which teachers form a favorable or unfavorable attitude toward the teaching and learning of mathematics with an appropriate technology.
3. *Adapting* (decision), in which teachers engage in activities that lead to a choice to adopt or reject the teaching and learning of mathematics with an appropriate technology.
4. *Exploring* (implementation), in which teachers actively integrate the teaching and learning of mathematics with an appropriate technology.
5. *Advancing* (confirmation), in which teachers evaluate the results of the decision to integrate the teaching and learning of mathematics with an appropriate technology. (Niess et.al., 2009, p. 5)

So, every participating teacher, according to the instruments used and the analysis done, had a starting TPACK and practice level. Then after every iteration, that level is checked again to see if it improved or slide down. In addition, every teacher will list the inhibiting and assisting factors that came in the way of his improvement (or decline) in TPACK and practice levels. In what follows, a briefing of the study results.

7. Results

According to teachers' practices, the intervention showed two major results. The first result was an increase in using GeoGebra in most stages assisted by teachers' ZPD (collaboration) and ZPA (knowledge and skills). When teachers applied the activities in collaboration with the researcher in an iterative way, this led to an increase in teachers' confidence which, in turn, led to an increase in the extent of using GeoGebra in each of their teaching stages. The second result was an increase in teachers' appreciation of GeoGebra as a teaching tool. This appreciation was reached because of the following characteristics of the GeoGebra activities applied by the teachers: a) the effectiveness of the GeoGebra activity, b) the ease of operating the software by students, c) the strong alignment between the activity and the curriculum, and d) the strong fit of the activity with the instructional strategies each teacher uses.

During my first meeting with Hazem, I asked him: "*What do you want to teach as a first lesson with* GeoGebra?" Hazem replied: "*I don't know; I thought you will give me ideas or something ready to apply."* I suggested for him a discovery activity and explained how to conduct it to which he commented:
This is a nice idea, very nice idea, I never thought of it like that. To deduce something by students is not an easy task. My class is so heterogeneous. The idea you suggested is very nice. (Interview 1)

After implementing the activity, he said:

> The activity was straight to the point and it optimally supported the curriculum requirements. This activity was tailor- made, easily done by students… I used to do things differently. (Interview 2)

Upon asking Sara about her general opinion regarding her teaching experience with *GeoGebra*, she said:

> [Using GeoGebra in my teaching] increased motivation for the class because each student was able to try and check his/her answer before answering. Also, I saw all students were involved, I saw no one not focusing. I liked the idea to do the activity by students in the lab I felt students more involved and more serious. (Interview 3)

Concerning the teachers' TPACK. Before the intervention, most participants' subcategories were at the "adapting level" and after two iterations they reached either the "exploring" or the "advancing level" (highest TPACK level). The change was mostly dynamic with change happening immediately after the first implementation. There were some assisting factors to higher TPACK levels mainly collaboration (ZPA) and increase in knowledge and skills (ZPD), and some ZFM factors like availability of hardware, curriculum requirements and students' motivation. The limiting factors were mainly ZFM factors such as: not enough available or accessible hardware, lack of time to prepare and conduct GeoGebra activities, students' motivation, and curriculum requirements…and one ZPD factor lack or not enough skill.
For example, Amani stressed a lot on the importance of collaborating with a professional in order to reach higher TPACK levels in the "teaching" subcategory; she said:

> You have a very important role. I was encouraged to work because you will come to see me and (see) my work. I have lots of work to do but I specify time for GeoGebra because I know you are coming to see me. (Interview 2)

Also, in our last meeting she said: "I think someone should help teachers make model lesson; your presence helped a lot. I will do the same when I will do workshops for my colleagues*"* (Interview 3).

When Tima was asked whether the intervention affected her own mathematical content knowledge and, if so, to what extent, she said:

> Frankly yes. For instance, the space topic, I myself understood it better. I am talking seriously. Now, as a teacher and I know the material but now after seeing and moving things I understood them better and could imagine them [space problems] better and easier. If I could see such things at university, I could understand better. I knew the rules, if I took them in this way [graphs] I could have related things together [many things together]. (Interview 3).

In terms of the impact of the intervention on teachers' zones, the GeoGebra intervention done cooperatively and iteratively resulted in: 1) decreasing participants' ZFM effect and also made participants experience the discrepancy between their expected and actual barriers for technology integration, 2) filling participants' ZPA technology integration gap that they had from their preparation background and previous professional developments, and 3) affecting participants' ZPD in a non-equal manner, but ending in the same result after the intervention.
For example, Amani did not have enough preparation in her college study or in her school professional development about the effective ways to integrate technology in her teaching (low assistive ZPA). She also did not feel confident with her knowledge and skills concerning that aim (low assistive ZPD). In addition, she was facing many external factors to her technology integration (high limiting ZFM). When asked why she did not apply what she had learnt from the workshops she attended, she replied:

> I didn't apply due to many reasons (personal and availability of hardware) but now I am happy exploring things and learning a lot. Your presence made me work because I felt more confident, secure, and somehow ethically obliged. (Interview 1)

On her third meeting she said:

> After this experience (the three iterations) not only I got more confident in using GeoGebra but also working with GeoGebra made me more self-confident to teach my students. Sometimes students ask strange and difficult [challenging] questions, but now I am more confident since I can imagine the figures [3 D problems figures] better than before. (Interview 3)

In my first meeting with Sara, she said:

> I saw applets online on this chapter [functions] but the idea I don't know what to do or what part of the chapter to introduce first. (Interview 1)

But after implementing her first lesson she stated:

> After this experience [applying GeoGebra activity] for the first time and in a lab. I liked a lot to use GeoGebra in my teaching and I will change a lot of things in my teaching from now on especially that I have a computer lab available now. (Interview 2).

In summary, due to the collaborative and iterative nature of the intervention, also due to the power of the GeoGebra software and its ease of use all four participating teachers have increased in their TPACK level, more use of GeoGebra in their classes, shift from teacher-centred to student-centred of GeoGebra use. And most importantly, teachers got over most of the hindering factors. As a result, all four teachers became better designers. In what follows we will discuss those results.

8. Discussion

An important component of the collaboration that was used in this study is teachers' collaboration with the researcher himself. Not only is this an essential component of DBR **(Wang & Hannafin, 2005)**, but it also has played a role in teachers' willingness to integrate GeoGebrain their teaching. **Drijvers et al. (2014)** assert that technology educators support teachers in planning and implementing technology-enhanced lessons. **Rogers' (2003)** innovation diffusion theory (IDT) posits that one of the characteristics of change agents that can facilitate the innovation adoption and diffusion process is their credibility. In fact, teachers are more willing to change their classroom practices and apply them appropriately when they work with an individual who is an expert **(Darling-Hammond et al., 2009)**. In the case of this study, the researcher is a practicing secondary mathematics teacher just like the participants, which may have increased teachers' receptiveness to the intervention.

Yet another important factor in terms of the design of the intervention was its iterative nature which allowed for a more sustained professional development that was based on regular one-on-one follow-up with the participating teachers. Ongoing feedback that is catered to individual needs **(Lawless & Pellegrino, 2007)** ensures that continuous learning occurs **(Webster-Wright, 2009).**It also allows more opportunities for reflection which has been shown to promote teachers' examinations of their beliefs and how they can change them **(Orrill, 1999).**In addition, allowing teachers to reflect on their lesson implementations provides them a better understanding of the physical and social context in which they work **(Mouza, 2011).** In fact, this was evident in this study whereby the teachers became more aware of the *real* barriers that were impacting their GeoGebraintegration. Reflection is also essential for the development of TPACK **(Mouza, 2011).**

All four participants in this study used GeoGebra to demonstrate certain lessons before the intervention and, then, shifted to computer lab student-centred discovery activities during and after the intervention. When teachers shift their role from demonstration to active learning, they become more than just technology users; they become activity designers. Teachers, in their early technology integration stages, mostly use demonstration at first and then slowly allow their students to use computers **(Laborde, 2001).**Teachers will not reach this level unless they feel more confident with the technology and have higher TPACK **(Laborde, 2001).** Similar results were found by **Figg & Jaipal (2012)** who listed four phases that teachers pass through to become activity designers: 1) modeling a tech-enhanced activity type (learning with the tool), 2) integrating 'pedagogical dialog' in a modelled lesson, 3) developing technological knowledge (in context) through tool demonstrations, and 4) applying TPACK-in-Practice to design an authentic learning task. In order for teachers to transition from demonstration to active learning, they need scaffolding from a professional to give them more confidence and to promote the development of new TPACK.

Misfeldt y Zacho's (2016) study confirms that by showing that actively positioning teachers as designers, and supporting them in developing their own digital materials, seems to boost their tendency to take ownership of the developed material. When teachers develop their own scenarios, they are inclined to take an active stance on learning goals and teaching methods. Furthermore, the collaborative nature of the work opens up a discussion among peer teachers together with the possibility of discussing with researchers.

In transferring their TPACK to practice, teachers take instructional, curricular, and organizational factors into consideration **(Ertmer & Ottenbreit-Leftwich, 2009).** Even learning activities associated with technology within the school system might be considered by teachers as extra to the curriculum **(Handal et al., 2013).** Therefore, one solution for sustainability in technology adoption in practice is the "person-in-practice-in-person" approach

(Lerman, 2001). The study results were not meant to be generalized but to understand more in depth the teachers' stages of GeoGebra (technology in general) adoption phases. This study had many limitations that are presented in the following paragraph.

9. Limitations and recommendations for future research

This study paves the way for numerous possible research avenues. First, the intervention can be conducted on teachers who are unmotivated or resistant to integrate technology in their teaching as their technology adoption process might look different from what was found in this study. Second, in order to start building the generalizability of the results of this study, future studies should be conducted on larger sample sizes and across teachers from various geographic regions. Increasing generalizability also requires that research be done on pre-service mathematics teachers and on teachers in the public sector. These two groups of teachers may experience different limiting or assistive factors to their technology integration or show different developmental stages in their teaching practices and TPACK. Third, another extension of this study could be to determine the impact of the intervention on students' achievement and, potentially, the mediating impact that teachers' zones, practices and TPACK had on student achievement. Fourth, it is recommended that the DBR methodology be used for future technology professional development research. Fifth, data collection in future research should also include classroom observations to provide a more accurate and comprehensive picture of teachers' process of technology integration. Sixth, this study suggested the use of the Ladder and Slide framework to explain teachers' stages of technology integration. This framework was accepted to be published in a prestigious journal and it is under review now as an immediate result of this study on the theoretical level. Future research can be done to determine the usefulness of this newly proposed framework.

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