Chapter 5
Applying TPACK-P to a Teacher Education Program

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We propose a teacher community called the learning module design team (LMDT) in which preservice teachers, in-service teachers, and science education researchers work together to enhance each other's TPACK-Practical (TPACK-P). Within the teacher community, in-service teachers designed physics learning applications (APPs) and learning modules with their TPACK-P; preservice teachers then tested the APPs and implemented them into their microteaching. Designing these APPs and learning modules allow in-service teachers in the community to refine their TPACK-P, while implementing these artifacts develops preservice teachers' TPACK-P. A professor who was also a physics teacher educator and science education researcher played the role of a facilitator, ensuring within- and between-group communication. Besides elaborating upon each other's TPACK-P, the LMDT developed a total of 12 android APPs on multitouch tablets to help students better understand physics concepts such as spring resonance, slingshot physics, and friction. This chapter presents the design principles, functions, and features of the 12 APPs; it also describes how these teachers collaborated with each other within the community.

5.1 Introduction

The pursuit of technocentric class instruction has been popular since the last decade of the twentieth century; recently, more focus has been placed on digitizing the

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content of teaching and learning as well as on teacher quality. In traditional physics classrooms, teachers often use analogy as an instructional strategy to help students imagine and comprehend abstract concepts. Conceptualizing the atom as similar to the solar system is one example (Harrison & Treagust, 1993; Podolefsky & Finkelstein, 2006). Nowadays, with help from computers, multimedia applications can effectively present micro- or macrophenomena in science and make learning interactive and individualized (Ainsworth, 2006; Mayer, 1999; Plass, Chun, Mayer, & Leutner, 1998; Teasley & Rochelle, 1993; Wu, Krajcik, & Soloway, 2001). The unobservable, abstract concepts (i.e., waves, projectile motion) or imaginary analogies can be visually concretized or idealized through simulation, thereby lowering the cognitive demands on students (de Jong & van Joolingen, 1998; Goldstone & Son, 2005). Selecting and using appropriate technology to make context instruction more comprehensible requires teachers to develop their technological pedagogical content knowledge (TPACK; Mishra & Koehler, 2006).

Curriculum digitization is not the same as curriculum computerization. Pedagogical concerns and technological affordances need to be considered. Experienced teachers know what their students need in learning, as well as what they need to make their teaching more comprehensible. Therefore, in this chapter, we propose a teacher community that develops and reinforces the bidirectional development of both experienced teachers' and preservice teachers' TPACK in teaching practices (TPACK-Practical). Experienced teachers designed simulation-based applications (APPs) and learning modules for preservice teachers to use; the feedback from the users (preservice teachers and students) was then directed back to the designers (in-service teachers), offering them information to use when improving their APPs and modules as well as elaborating their TPACK-P. The TPACK-P of teachers with different proficiency levels was believed to be elaborated through the tasks of designing, implementing, and modifying these learning APPs and modules. This chapter also offers the design principles used when developing the learning APPs, as well as the major features of each APP, in order to inform future designers of science learning software.

5.2 Simulations for Science Education

ICT-based interventions can either be used to enhance the practical investigation or as a virtual alternative to real practical work where a simulation supports exploration of the investigative model through a computerized representation of the phenomena under study (McFarlane & Sakellariou, 2002, p. 221).

Science is a subject that demands students explore the natural world, and simulations can offer imitation or operational models and interactive environments to make complex or inaccessible phenomena friendly to users. Research also found simulation a useful tool for constructing students' understanding of concepts, developing their scientific inquiry abilities, and enhancing their science learning motivations (Baxter, 1995; de Jong & van Joolingen, 1998; Eylon, Ronen, & Ganiel 1996;

Goldstone & Son, 2009; Reid, Zhang, & Chen, 2003; Rutten, van Joolingen, & van der Veen, 2012; Zacharia, 2007; Zacharia & Anderson, 2003). Since teachers' attitudes toward and intentions for teaching with simulations influence their choice of appropriate teaching models or activities (Zacharia, 2003), preparing science teachers to be knowledgeable about and competent in using simulations will be fundamental in promoting teachers' uses of simulation-based curricula to assist student science learning.

5.2.1 Simulations in Science Learning

Interest in pursuing simulation applications for science teaching and learning has increased in recent years. The Physics Education Technology (PhET) project, which created and released approximately 50 simulation-based programs for physics teachers worldwide, was one such successful effort focused on physics learning and teaching. These simulations were created for "supporting students in constructing a robust conceptual understanding of the physics through exploration" (Perkins et al., 2006, p. 18). To achieve such a goal, interactive animations or responsive systems are purposefully built to encourage students' self-explorations. Simulations in Java™ or Flash® format offer easy access for students seeking to perform scientific explorations or for teachers looking to demonstrate phenomena in their lectures (Wieman, Adams, Loeblein, & Perkins, 2010). These simulation-based learning tools can be embedded into learning modules. For example, Chang, Chen, Lin, and Sung (2008) constructed a thematic course about optical reflection and refraction in which students were hypertext prompted to activate their prior knowledge and engage in scientific inquiry through the manipulation of built-in simulations (e.g., make, test, and form conclusions about their hypotheses). Web-based inquiry science environment (WISEm 1996–2003) is another example of how simulations can be implemented to assist students' self-directed or group inquiry learning tasks.

5.2.2 Tablet PCs as Good Carriers of Simulations

Tablet PCs (hereafter called tablets) are small, portable computers that are lightweight, reasonably durable, and mobile. Tablets can do most of what home computers do (though often with less advanced functions); however, they offer teachers better control and versatility in displaying content, making impromptu edits, and switching between programs and other applications (Mock, 2004). Built-in sensors (e.g., accelerometers, gyroscopes, and gravity sensors) make tablets sensitive to users' body motions, where the kinetic and haptic experiences involved in learning with built-in sensors reinforce students' mental representations and concept construction (de Koning & Tabbers, 2011; Wang, Wu, Chien, Hwang, & Hsu, 2015). The tablet's multitouch screen, which receives input from single or multiple users simultaneously, encourages efficient and equitable participation among group members during their discussion and collaboration efforts (Marshall, Hornecker, Morris, Dalton, & Rogers, 2008; Piper, O'Brien, Morris, & Winograd, 2006; Rick, Harris, Marshall, Fleck, Yuill, & Rogers, 2009). All these sensors make tablets function like microcomputer-based laboratories (MBLs), which allow students to construct their inquiry ability by engaging them in tasks of data collection and analysis.

5.2.3 Design Principles for Simulation-Based APPs and Learning Modules

Based on previous studies regarding how simulations and tablets can be implemented in teaching and learning, we developed design principles that should be considered when designing simulation-based APPs for physics learning. These include:

Concept Construction Scientific principles, concepts, and facts can be embedded in simulations wherein students can explore and construct conceptual and operational models (de Jong & van Joolingen, 1998).

Model Exploration Programmers set formulas with default values and predefined ranges of parameters in order to allow complex natural phenomena to be examined through variable manipulation activities or virtual experiments (McFarlane & Sakellariou, 2002). Students interact with these model-based learning programs, allowing them to practice and strengthen their scientific thinking (e.g., variable identification or manipulation, hypothesis, or model testing).

Real Data Collection Built-in sensors (e.g., gravity or multitouch sensors) make tablets function much like MBLs. Students can have personalized and rewarding science learning experiences when they are encouraged to actively use MBLs to collect data and make related analyses (Thornton & Sokoloff, 1990).

Format Flexibility Using appropriate pedagogy (e.g., predict–observe–explain [P–O–E], inquiry learning) to support simulation implementation in science classroom contexts facilitates student learning about the nature of science (Monaghan & Clement, 1999).

These design principles indicate that the designers of science learning APPs need to be equipped with professional knowledge not only in the target science topics and programming but also in the pedagogy of teaching and learning the target scientific concepts or practices. Teachers can be good curriculum designers because they are experts in knowledge delivery and student learning progress; but they may lack knowledge and experience with technology-infused curriculum design because, in most cases, they are not programmers (Sandholtz & Reilly, 2004). Professional programmers do not normally make good curriculum designers either because they lack professional knowledge about science teaching and learning. Therefore, to design and develop effective science learning APPs requires a team that is composed of both science teachers and programmers. The more teachers and programmers there are on the design team, the more pedagogically advanced the instructional artifacts are likely to be.

5.3 Development of Teachers' TPACK-P

Simulation-based APPs can be used as tools by teachers to assist their instruction or as curricula by students seeking self-study. To design, develop, and implement these curriculum-driven, technology-assisted learning tools demand not only a profound TPACK but also related teaching experiences. It is not necessary to view the instructional artifacts that teachers produce fully developed end products ready for wide-scale educational use; rather, these technology-infused tasks can be viewed as activities in the professional learning journey for teachers. Considering that TPACK is dynamic and situated in the context and nature of the learning situation (Cox & Graham, 2009; Doering, Veletsianos, Scharber, & Miller, 2009; Mishra & Koehler, 2006), teachers can develop and refine their TPACK through actions in the design–implementation–evaluation–modification cycle.

5.3.1 TPACK for Curriculum Designing

How teaching material is designed or implemented into instruction requires teachers' deliberation on factors that influence student learning of the target learning outcomes (e.g., concepts, affect, skills, practices/processes, etc.). According to Shulman (1986), teachers with well-developed pedagogical content knowledge (PCK) are able to identify:

The most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations including an understanding of what makes the learning of specific concepts easy or difficult, the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning. (p. 9)

All of these pieces of knowledge fulfill the qualification requirements for effective teachers of disciplinary content. As teachers gain more experiences in teaching, teachers' PCK is transformed into *craft knowledge*, which refers to the personally constructed wisdom that teachers rely on to facilitate their instruction. In that sense, we can assume that experienced teachers' PCK serves as both a benchmark and an objective for preservice and/or novice teachers.

Technology-rich learning and teaching environments are an additional component to contemporary PCK. Therefore, as technology is more and more often considered and added to the framework of PCK, expanding teachers' knowledge of teaching with technology—their TPACK—becomes a necessary capability for contemporary teachers (Mishra & Koehler, 2006). Situated mapping of technological affordances, representations, pedagogy, and learners for different subject topics is important to further transform teachers' TPACK into an active knowledge that embraces student learning (Angeli & Valanides, 2009). Tsai and Chai (2012) proposed the term *design thinking* to describe the essence of teachers' TPACK and defined it as convergent knowledge for teachers to use in creating teaching practices where technological advances are meaningfully applied to support teachers' curriculum design and implementation.

5.3.2 TPACK-P Through a Teacher Community

Designing simulation-based APPs for science teaching and learning demands requires that teachers start with comprehensive considerations of content, learners, and pedagogy within the specified disciplines, topics, and learning outcomes. Activities like curriculum designing and instructional enactment allow designer teachers and practitioner teachers to develop and further refine their TPACK. We assume such TPACK is later transformed into TPACK-P when they design and implement simulation-based APPs to assist their science instruction through stages of design and planning, enactment, and assessment (see Chapter 2; Yeh, Hsu, Wu, Hwang, & Lin, 2014). Given that TPACK-P is experience based and personally constructed, teachers within the teacher community with different levels of TPACK-P can receive different levels of assistance from community members in an ever-changing mentoring dynamic.

"Teachers helping teachers" is the main reason why teacher communities are a necessity (Feiman-Nemser, 2001, p. 1043). All practicing teachers in the community support each other when solving instructional problems and planning for their solutions' sustainability. Mentors rationalize their interwoven considerations when mapping technological affordances to specific subject-area content (C. Chang, Chien, Chang, & Lin, 2012) or offering explicit support to assist preservice teachers in designing instructional artifacts (Koehler & Mishra, 2005). Their mature pedagogical insights and teaching experiences can be good resources to help preservice teachers address the theory–practice gap; but in fact, these experienced teachers also benefit from interacting with novice teachers and encountering their energy and idealism. Novice teachers in most cases have higher levels of technological literacy than experienced teachers—they are the *Net Generation* and likely bring contemporary information about advanced digital electronics and innovative uses of these technological tools to the educational context and their mentor teachers. Since teachers from various places in their career development have different backgrounds, specializations, and beliefs, a community where teachers can learn from each other and offer different perspectives is constructive to teachers' instructional quality and to their own professional development.

Forming a teacher community where teachers with different TPACK-P proficiency levels and specialties participate offers these teachers a platform to share ideas and learn from each other. Teachers in the community can be learners and professionals at the same time, since they learn from each other (Abdal-Haqq, 1996; Lawless & Pellegrino, 2007; Newmann & Associates, 1996). Self and collaborative reflections among teachers, which we called critical collegiality, further boost teachers' reflecting-on-action and reflecting-in-action, intellectual virtues, and communicative skills (Lord, 1994). Such teacher collaboration can bring positive impacts to the quality and practicality of the instructional outputs as well as to the refinement of teachers' expertise. Other features such as offering longitudinal support and technology access are also factors sustaining teachers' participation willingness and the richness of the community.

5.4 Learning Module Design Team

Teachers' TPACK-P is complex knowledge constructs that are continuously refined by teachers' experience accumulation and regular practice in instructional design and enactment. With the purpose of developing learning APPs that can effectively facilitate physics teachers' instruction, we propose a learning module design team (LMDT) within which teacher educators, experienced teachers, and preservice teachers collaboratively work. Teacher educators and experienced teachers take the lead roles in designing instructional artifacts (e.g., APPs, learning modules), while preservice teachers reflect on their experiences with the APPs and provide user feedback in modifying the artifacts. These authentic engineering design, evaluation, and modification experiences further elaborate the TPACK-P of the teacher educators, experienced teachers, and preservice teachers who participate (Fig. 5.1).

5.4.1 APP and Learning Module Designers

The LMDT consisted of a teacher educator, four experienced physics teachers, and 11 preservice teachers who collaborated with each other on developing simulation-based physics learning modules. The professor had been educating physics teachers

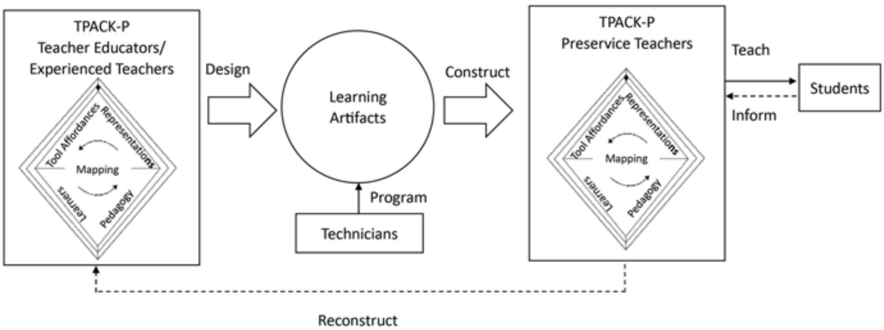


Fig. 5.1 Rationale of LMDT (Modified from Angeli & Valanides, 2009)

for over 20 years, while the experienced teachers had 19 years in teaching on average (43, 18, 10, and 5 years). These experienced teachers had collaborated with the professor on designing and evaluating physics curricula for an average of 9 years (13, 13, 6, 4 years). Regular group meetings were held for learning the APP and the learning module design and modifications. Figure 5.2 shows how the teacher community operated in actual practice.

Within the LMDT, four experienced physics teachers interested in APP development were responsible for the APP design. Among them, one teacher played the role of lead programmer. The discussions among the experienced teachers in the APP design meetings covered topics such as (a) what affordances of tablets could be useful to student learning, (b) what physics concepts students found difficult to understand and whether those concepts could be presented through APPs on tablets, (c) what learning objectives for each concept needed to be achieved, (d) how concretized or idealized concepts could be achieved and presented, and (e) the possible models that would activate the mechanism of the target concepts. They endeavored to seek a balanced mapping of content representations, the unique affordances of tablets, learners' cognitive development, and pedagogy for each APP and concept. For example, they believed that the built-in gravity sensors in tablets could be effective tools for students measuring the components of gravitational field strength and help them to physically sense the gravity and visualize how projectiles move on a trajectory. Therefore, they included principles of independent motion so that students could conceptualize how motion is influenced by its initial speed and gravity through manipulating and interacting with the APPs.

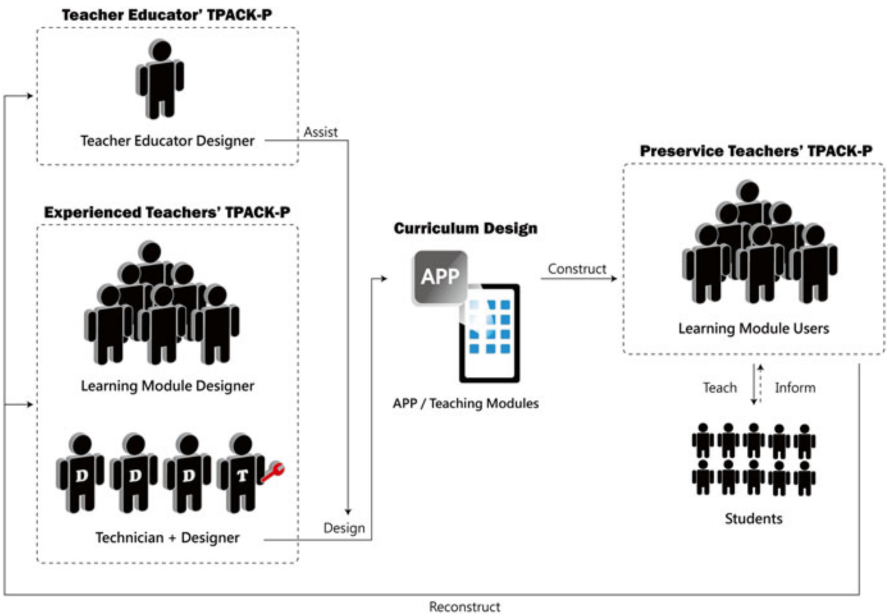


Fig. 5.2 Actual practice of the LMDT

The prototypes of these APPs were later sent to the learning module designers who were experienced teachers and members of the larger teacher community (though not involved in the APPs' design). These designers were encouraged to familiarize themselves with these APPs, comment on how to make these APPs more friendly and meaningful to their users, and generate learning modules for use when teaching with the associated APPs. Their user feedback was collected and considered by the designers when improving the learning APPs. When developing the learning modules, these module designers shared how they taught related concepts and how their students might react to the use of the APP. Through several discussions, they all agreed that the P–O–E approach would be a useful strategy for guiding students' learning of projectile motion while using the simulation-based APPs. Finally, these experienced teachers developed learning modules with guiding questions and suggested steps for teachers to use in helping students acquire the concepts of projectile motion and scientific thinking.

These two groups of experienced teachers (the APP designers and learning module designers) refined their TPACK-P as they produced, reflected upon, and evaluated the APPs and corresponding learning modules. Their TPACK-P was further shaped by their negotiating of an array of factors critical to instructional artifact design, such as what scientific models needed to be embedded, how the scientific phenomena were presented, who the target students were, and where these APPs and learning modules could be used. It is the engineering design process (e.g., invent, evaluate, revise) that repeatedly requires teachers to engage best solutions and then develop beta versions of the APPs, which science teachers can then use to assist their science teaching.

5.4.2 APP and Learning Module Practitioners

Preservice teachers comprised the other part of the LMDT; they played dual roles of artifact practitioners implementing the APPs and of outsider APP testers. They represented and offered user feedback from the perspective of teachers not experienced in teaching with technology or using such APPs and learning modules. Their personal use and implementation experiences in microteaching and teaching internships provided a fresh perspective for the APP designers.

Learning from exemplar teachers and through actual teaching practices is a direct way of developing preservice teachers' TPACK-P. The professor of the LMDT, who was also the instructor of the physics teaching practicum, provided each preservice teacher with a tablet when the course began in order to familiarize them with tablet manipulation. He rationalized how the APPs and learning modules were designed and demonstrated how these APPs and modules could assist them in their future physics instruction. While implementing the APPs in their teaching, these preservice teachers were able to generate some innovative instructional uses; they also brought in feedback from high school students responding to the use of these APPs. These innovative uses and user feedback were later collected for the APP and learning module designers to use in improving the original APPs and modules. Newer versions of the APPs were created to better serve both teaching and learning needs as well as to address different educational purposes. For example, the original Spring Resonance APP only allowed users to drag and use one mass in each trial, but the newer version allowed users to drag and use up to three different masses in trial tests. Displaying the resonance of three springs with different masses together was expected to help students better visualize the resonance with comparisons and under controlled conditions.

5.4.3 Examples of the APPs

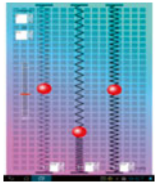
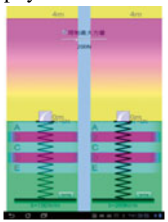
The physics APPs and learning modules have repeatedly been improved and expanded to better accommodate teachers' and students' needs, based on feedback from teachers who used the APPs within the LMDT, from teachers participating in other professional development workshops, and from high school students who used the APPs as part of their science classes. The descriptions, functions, and distinctive features of the 12 APPs are listed in Table 5.1.

5.5 Final Remarks

Physics APPs and learning modules were the main products of the "Aim for the Top University" project. This project was missioned with finding ways to prepare a friendly science learning environment and quality science teachers for the digital era and to equip students with good science concepts and scientific thinking. The underlying mechanism for running a teacher community (i.e., the LMDT) involves valuing and allocating teachers' wisdom and heterogeneous TPACK-P proficiencies through an engineering design cycle of invention–trial–feedback–redesign of instructional artifacts. Participating teachers were expected to develop and refine their TPACK-P from their tangential involvement not only in the APP and learning module development but also through their collaborations with other teachers. Iterative and multidirectional experiences transformed preservice and in-service teachers' TPACK-P through authentic collaborative practice for the mutual benefit of all.

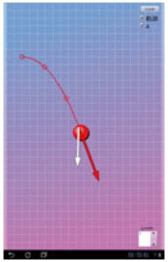
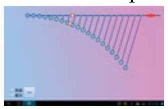
We also established and presented the rationales for and design features of simulation-based APPs for science teaching and learning. These simulation-based learning APPs were designed to allow students to explore abstract physics or unobservable scientific phenomena by engaging them in simultaneous haptic manipulation of multiple variables. Based on an empirical study that we did for knowing the effectiveness of the APPs we developed, high school students showed improvements in their understanding of projectile motion and collision after taking the module-based course where related APPs and the strategy of P–O–E were implemented (Wang et al., 2015). Considering that simulation-based learning APPs on mobile devices can make science teaching and learning less effortful, it is worthwhile

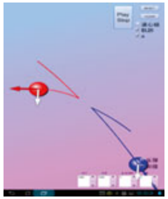
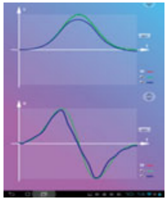
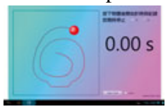
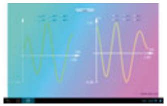
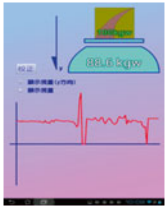
Table 5.1 Features of the physics APPs

Physics learning APP	Description	Multitouch[a]	Built-in sensors[b]	Kinetic manipulation[c]	Experimentation[d]	Variable manipulation[e]
Spring resonance 	Three mass–spring systems with different nature frequencies were placed on the tablet screen. Each system consisted of a mass with a spring on both ends attached to a wall. Users can move the mass up and down by tilting the tablet to a different angle. They are expected to find the right frequency of tilting motion so that one of the springs is in resonance with the motion.	X	X	X	X	X
Slingshot physics 	Two slingshots with different spring constants (k1, k2, k2 = 2*k1) are built in the APP for users to predict which slingshot would shoot their projectile as far as possible under the condition that the maximum force stretching slingshots each time remains the same. Users can explore how the tension of the slingshot influences the distance traveled.	X			X	X

(continued)

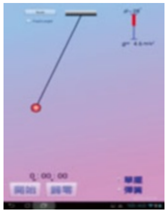
Table 5.1 (continued)

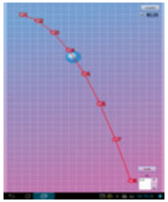
Physics learning APP	Description	Multitouch[a]	Built-in sensors[b]	Kinetic manipulation[c]	Experimentation[d]	Variable manipulation[e]
Friction 	Static friction coefficients can be calculated in terms of the maximum angle that can be reached before one of the items begins to slide. Users can place an object on the top of the tablet and find the friction coefficient from the built-in angle-measuring program by raising one side of the tablet. This APP allows users to adjust frictions (μ_s, μ_k) and see the vectors of force and acceleration from the arrows displayed on the screen to help understand the force reactions from acceleration, gravity, and friction.	X	X	X	X	X
Projectile motion 	Users can finger press the tablet screen to see projectiles and set the initial speed of the projectile by dragging their fingers. After releasing their fingers, these projectiles will move due to the physics laws. Users can see how the magnitude and direction of gravity influence the motion of projectiles by tilting the tablet where the built-in gravity sensor can detect the angles between the tablet and the surface. Trajectories of the projectiles can be displayed, helping users to visualize how different variables (e.g., speed, gravity) in physics laws contribute to the projectile motion. Similar concepts: Curtain Throw 		X	X	X	

Collision 	Users can explore what factors contribute to the collision of two objects by changing the velocity, the direction of motion, etc. The APP allows users to set up the initial conditions of the projectiles (e.g., direction, speed) by touching and applying pressure on the projectiles. Pressing the “Play” button on the top-right corner starts the motion of the two objects with preset conditions. Users can display the trajectories and the vectors involved in the motion for better visualizing and understanding how gravity and velocity interact onto the moving objects.		X	X	X	X
Graphs of motion 1-D 	The APP is built-in with some predefined V–t graphs and offers blank graphs for users to draw X–t and/or a–t graphs for different V–t graphs. In order to let users visualize possible interactions of their predictions, the APP can display the corresponding V–t graph from the user’s X–t and/or a–t graphs (with different colors). Similar concepts: Graphs of Motion 2-D  			X		
Visual weight 	This APP uses the built-in sensors of the tablet (i.e., gyroscope and gravitational sensors) to allow users to see how gravity influences the visual weight of the objects. By tilting or flipping the tablet, users can observe how the visual weights correspondingly change according to the varying acceleration.		X	X	X	

(continued)

Table 5.1 (continued)

Physics learning APP	Description	Multitouch[a]	Built-in sensors[b]	Kinetic manipulation[c]	Experimentation[d]	Variable manipulation[e]
Pendulum 	Users can observe the oscillation of the pendulum by dragging the pendulum drop, adjusting the mass, and changing the gravitational acceleration by tilting the tablet. Students can calculate its frequency period based on the data collected from the built-in timer. Variables like angles, length of the drop, and mass of the pendent can be changed. They can also observe and discuss the simple harmonic motion of the spring–mass particles.		X	X	X	X
Find the center of mass 	This APP uses the built-in sensors (i.e., gyroscope, gravitational sensors) to familiarize students with the approach that physicists use to find the center of mass for objects. Users can flip the tablet around to find the center of mass for the tablet.		X	X	X	

Dot to motion 	Users can draw the motion trajectory and make explanations in practices with different conditions by setting moving speeds at 2 m/s in gravitational fields. The mesh in the background helps users find where the dots are at the x and y axes.			X		

Note
[a]Multitouch: Enables the function of more than two simultaneous touch points
[b]Built-in sensors: Enable the built-in sensors of tablets (e.g., accelerometers, gyroscopes, and gravity sensors) to help students experience science phenomena or collect related data
[c]Kinetic manipulation: Engages students to physically interact with tablets to understand abstract concepts. For example, students can see and feel weightlessness in the Visual Weight APP when the tablet is thrown into free-fall motion
[d]Experimentation: Simplifies the context and tries to construct an ideal environment for students to do experiments
[e]Variable manipulation: Allows users to manipulate variables and see the results

for teacher educators to initiate an engineering design cycle for building an authentic and effective teacher community where they can benefit from mutual support or to customize curricula together based on their needs. All these endeavors will ultimately lead to the enhancement of student learning.

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