Abstract—The purpose of this study is to develop problem-solving based learning tools to nurture sound knowledge and abilities about “Information Studies (or Informatics)”. Based on the survey on Japanese high school students’ comprehension of communication networks, our first tool focuses on teaching the basic principles of network protocols. This tool gives students hands-on experience to help them understand. In this paper, we describe the conceptual design and preliminary evaluation of this tool.

Keywords—network protocol; data link layer; asynchronous communication; high school students; learning tool; hands-on device

I. INTRODUCTION

Recently, many countries have started innovative national curricula based on 21st century skills and computational thinking [1-6]. In an OECD report, 21st century skills are important key competencies for new millennium learners [7]. The important 21st century skills are ICT related skills, abilities and knowledge. Therefore, the learning objectives of computational thinking (CT) are included in a wide range of the 21st century skills [8].

Moreover, Wing pointed out the importance of educational opportunities related to computational thinking for college/university freshmen and pre-university students [9,10]. CATA and ISTE discussed the possibility of bringing computational thinking to K-12 [11]. Actually, some schools/ universities in the world have already started new courses on CT education [12].

In Japan, CT related education has been taught in elementary school through to high school since 1985 [13-15]. In particular, “Information Studies” has been a compulsory subject for all students since 2003. The core curriculum for information studies focuses on three points: ICT fluency, scientific aspects of ICT, and digital citizenship. Both educational methods and learning tools are important to teach these points. Therefore, we focus on the development of problem-solving based learning tools to nurture sound knowledge and abilities.

II. PREVIOUS RESEARCH

In this section, we show the results of our survey on Japanese high school students’ comprehension of communication networks and our survey of previous research that deals with network protocols.

A. Fundamental Surveys of High School Education

To design an appropriate learning tool related to topics about information and communication networks, we examined high school students’ and university freshmen's comprehension of these topics through a simple mind map [16]. A simple mind map consists of nothing but nodes with a word and edges between nodes.

1) Methods

The subjects were 270 high school students (1st, 2nd and 3rd year students) and 96 university freshmen. We asked them to draw a simple mind map about “information and communication networks” from three aspects of core topics in information study. These maps were called student maps. Also, we made a “text map” based on some textbooks authorized by the Japanese government for information studies at high schools. This text map had 91 words. From all the student maps, we (1) counted the number of words in each map, (2)
separated all the words into two groups: formal (in the text map) and informal (not in the text map), and (3) counted the frequency use of all the words.

2) Results

Based on (1) and (2), there was no significant change in the number of formal words for only “the scientific understanding of information” related to the school year of the subjects. Therefore, the comprehension level of this domain does not change or does not increase at the developmental stages from 1st year in high school to freshmen in university.

Based on the text map, (2) and (3), we created comprehension maps of our subjects as shown in Fig. 1 (a) and (b). The comprehension map has 8 divisions: internet, packet switching, network protocol, file transfer, security, e-mail, data transmission speed and network services. Based on the text map, (2) and (3), we created comprehension maps of our subjects as shown in Fig. 1 (a) and (b). The comprehension map has 8 divisions: internet, packet switching, network protocol, file transfer, security, e-mail, data transmission speed and network services. The gray "Information and Communication Network" part is the core topic. The black divisions are divisions with a recognition rate of more than 50%. The white divisions are divisions with a recognition rate of less than 5%. In particular, there no descriptions of network protocols at all. Of these divisions, only 3 had all of their words described by 10% or more of the high school students in their maps. In the case of university freshmen, this number increased to 5 divisions. On the other hand, 3 divisions had no words described: protocol, file transfer and data transmission speed.

As a result of our survey, we found that knowledge of basic network principles was lacking. Therefore, we developed our learning tool to focus on teaching the basic principles of network protocols. Our tool gives students hands-on experience to help them understand.

B. Learning Materials for Network Protocols

We researched previous studies that deal with network protocols. The results are shown in Table.1. The OSI layers are shown in the left column, while the other columns are for previous studies. A [ ✓] symbol indicates that the layer is examined in the study.

The research in column A is a transmission code synthesis simulator [17]. This is a learning tool to teach data structures for a particular protocol. Using this tool, the communication procedure and control system in the transport and application layers can be seen.

The research in column B is a kind of network simulator (ns-2) [18]. This tool is used to build a virtual network on a PC.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Learning Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>✓</td>
</tr>
<tr>
<td>Presentation</td>
<td>✓</td>
</tr>
<tr>
<td>Session</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>✓</td>
</tr>
<tr>
<td>Network</td>
<td>✓</td>
</tr>
<tr>
<td>Data Link</td>
<td></td>
</tr>
<tr>
<td>Physical</td>
<td>✓</td>
</tr>
</tbody>
</table>

Fig. 1. Comprehension maps.
In this tool, the state of the transfer of individual packets is shown using animation. Learners can intuitively understand the state of the communication.

The research in column C is another kind of network simulator (OPNET) that can also be used to build a virtual network on a PC [19]. Learners can intuitively understand the state of the communication and can see the change in network performance due to changes in the parameters.

The research in column D is a network construction simulator [20]. Learners build networks using virtual PCs, switching hubs, routers and network cables and they make TCP/IP and server settings. Learners can visualize the operation of the network and see the processing of packets in different layers between network equipment.

The research in column E is a learning tool for routing [21]. This learning tool is not a specific device, but uses an orange to resemble packets between multiple learners based on certain rules. Learners can experience communication errors such as collisions and deadlocks by moving the orange.

The research in column F is a hands-on model of the Internet [22]. Learners select a transmission code and destination terminal. Bit strings are represented with black and white balls. The transmission code is sent along the appropriate path to the destination terminal. This learning tool embodies information transmission and reception on the Internet.

All of these tools are designed for the network layer and above, so they are not intended for the physical layer or the data link layer. However, bit synchronization is an important basic concept of communication, so we chose bit synchronization for our learning tool.

III. ASYNCHRONOUS COMMUNICATION

There are two types of communication: synchronous and asynchronous. Bit synchronization is necessary in order to perform asynchronous communication. Synchronous communication uses a data signal line and synchronization signal line. Asynchronous communication uses only a data signal line.

Asynchronous communication with bit synchronization is shown in Fig.2. Data is sent from the receiver to the transmitter on a data signal line. The transmitter determines the transmission data and period T. The receiver determines an appropriate period R to estimate the transmitted data from the received signal on the data signal line. To determine R, the receiver requires a synchronization device that performs timing detection. The receiver determines the sample time for receiving data based on timing detection.

The definitions of the period and sample time are shown in Fig.3. The upper part of Fig.3 shows the transmitted data and signal from the transmitter side. The transmitter sends one data bit per period. In Fig.3, the transmitter sends 111001. The lower part of Fig.3 shows how the data is received. The method used to receive the transmitted data is follows:

At first, the receiver samples the received signal. Next, the sample time is shifted from the previous position. The sample time is shifted until the received data changes. If the data changes, sampling is done at the new sample time.

Also, the sample time to receive the correct data even under the influence of jitter is important. The effect of jitter on the received signal is shown in Fig.4. Jitter is the change in the period caused by transmission delay and a small shift in the period of the transmitter and receiver. The received signal in the upper part of Fig.4 has no jitter. In this case, the correct data can be received even if the sample time is set in the...
vicinity of the data switching time. The received signal in the lower part of Fig.4 has jitter. In this case, the correct data cannot be received if the sample time is set in the vicinity of the data switching time.

IV. ASYNCHRONOUS COMMUNICATION

One of the authors taught bit synchronization at university. The style of teaching only used a blackboard. The students were in their 3rd year of Computer Science & Engineering. There were a total of 90 students. The bit synchronization class lasted 45 minutes. On the final exam, one of the questions asked was the following.

Calculate how much faster (in percent) the receiver clock can be compared to the transmitter clock and still correctly receive the data using the following parameters: 8 bits, no-parity, 1 stop-bit, 9600 bps. Explain your calculations and each equation used.

The percentage of correct answers to this question was about 60%. In the first step students use the following two basic concepts of bit synchronization.

- Sampling interval is $1/9600$ sec that is measured in the receiver clock.
- The sample time is shifted by $1/19200$ sec from the point where the received data changes.

Approximately 20% of the students could not answer with these basic concepts.

They were students who studied Computer Science & Engineering for one and a half years. However, it was difficult to understand bit synchronization logically by teaching only using a blackboard.

V. CONCEPTUAL DESIGN

The concept of our learning tool is to have learners learn heuristically using trial and error. There are two parts to our learning tool: the transmitter and the receiver. The transmitter and receiver can perform one-to-many communication.

A. Learning Objective

There are 3-points to be learned by using this learning tool.

![Tool Image](center) and implemented tool (Transmitter on left side and reciever on right side).

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• Setting the period and sample time of the received data.
• Understanding that there are sample times for which the data can be stably received and cannot be stably received. The received data is not stable in the vicinity of the data switching time.
• Setting the sample time so that the correct data can be received when there is jitter.

As for the first point, learners configure the period and sample time themselves. As for the second point, the received data is stable except in the vicinity of the data switching time. As for the third point, the sample time should be set to half of the period so that the correct data can be received when there is jitter.

B. Tool Design

The learning tool proposed in this study assumes that the transmitter and receiver clocks are independent. In this study, we consider synchronization that adjusts these clocks.

Based on this assumption, we designed our learning tool as follows:

• We define the period to be 1 period of the clock. The period of the transmitter is denoted by $T$. The period of the receiver is denoted by $R$. At the start of learning, $T \neq R$.
• We define the timing to receive the data in one period as the sample time.

C. Implementation

Our prototype was implemented using the Processing [23] programming language and the Arduino [24] hardware platform. An image of this learning tool is shown in Fig.5. Upper area of left side shows the transmitter GUI. Upper area of right side shows the receiver GUI.

By using the Processing, the transmitter GUI provides the following settings:

: Period $T$
: Bit string to be transmitted
: Jitter

The receiver GUI provides the following settings:

: Period $R$
: Sample time

By using the Arduino, the transmitter sends the data in accordance with the parameters set in the transmitter GUI, while the receiver receives the data in accordance with the parameters set in the receiver GUI. This tool uses ZigBee for communication between the transmitter and receiver. The transmitter transmits a binary bit string that decides the period and sample time. The receiver determines the appropriate period and sample time by trial and error to correctly receive the bit string.

D. Transmitter

The transmitter GUI is shown in left side in Fig.5. This screen shows the data 11010 being repeatedly transmitted using a period of 500ms without jitter. Left side in Fig.5 (a) shows setting the transmitted bit string by using 0 or 1 buttons. The transmitter can arbitrarily set the data. Left side in Fig.5 (b) determines the period of the transmitted bit string using the slide bar. The slide bar can be set at 50ms intervals in the range of 50ms-1000ms. The number to the right of the slide bar is the time of one period. Jitter can be added to the transmitted bit string by clicking the button shown in left side in Fig.5 (c). Jitter can be set to values up to ±10% of one period. Left side in Fig.5 (d) is the transmitted data waveform reflecting the parameters set in (a), (b) and (c).

E. Receiver

The receiver GUI is shown in right side in Fig.5. This screen shows data being received using a period of 500ms and a sample time of 50% of the period. Right side in Fig.5 (a) is the data that has been received. The received data is sampled

Fig. 6. Participants in this experiment.
at the positions of the arrows shown in right side in Fig.5 (b). The spacing of the arrows (period) is set using the period slide bar shown in right side in Fig.5 (c). The slide bar can be set at 50ms intervals in the range of 50ms-1000ms. The number to the right of the slide bar is the time of one period. The position of the arrow (sample time) is set using the sample time slide bar shown in right side in Fig.5 (c). The slide bar can be set at 5% intervals in the range of 0% - 100%. The number to the right of slide bar is the sample time in percent of one period from the data switching time. The period and sample time of the arrows in right side in Fig.5 (b) are determined by the parameters set in right side in Fig.5 (c). Sampling the received data at the position of the arrows results in the numbers below the arrows. Right side in Fig.5 (d) shows the data string that results from sampling at the period and sample time that the learner set.

VI. PRELIMINARY EVALUATION

We conducted a preliminary experiment with university students and high school students. We evaluated the effectiveness of our learning tool in a simulated lecture given by a university professor. The high school and university students did not have the prerequisite knowledge of information and communication.

A. Method

1) Experiment with university students.

Research participants of this preliminary experiment were a total of 92 first year university students. We distributed one learning tool per group of 4 people to 13 groups (See Fig.6 (a)). The entire lecture was 40 minutes. In the first 10 minutes we gave a lecture on fundamentals of communication. In the last 30 minutes we conducted experiments with our tool.

2) Experiment with high school students.

Research participants of this preliminary experiment were a total of 26 first and second year high school students. We distributed one learning tool per person to 22 people and one learning tool per group of 2 people to 2 groups (See Fig.6 (b)). The entire lecture was 60 minutes. In the first 30 minutes we gave a lecture on the application of information communication networks. In the next 10 minutes we gave a lecture on fundamentals of communication. In the last 20 minutes we conducted experiments with our tool.

The following problems were given to the participants.

P1: How should you set the period and sample time of the received data?

P2: How should you set the sample time so that the correct data can be received when there is jitter?

P3: How should you set the period and sample time of the received data if 0000 and 1111 are transmitted alternately from the transmitter?

B. Result

The percentage of correct answers for each problem is shown in Fig.7. The percentage of correct answers for university freshmen was more than 60% for all of the problems (Fig.7 (a)). The percentage of correct answers for high school students was more than 80% for all of the problems (Fig.7 (b)). Especially, more than 90% of the answers to P1 were correct. Table.2 is a summary for university juniors, university freshmen and high school students.

C. Discussion

We also did a questionnaire survey about our learning tool. The following answer choices were presented to the participants.

- Could understand the concepts by using our tool.
- Could understand the concepts better by using our tool.
- Could understand the concepts without using our tool.

The questionnaire result from the university freshmen with correct answers is shown in Fig.8 (a). The amount of time that was spent on the experiment (45min) was shorter than the university lecture. The number of students who could understand the concepts by using our tool was around 30% for all the problems. The level of understanding using our tool was the same as the lecture even though there is no prerequisite knowledge.

| TABLE II. SUMMARY OF PRELIMINARY EXPERIMENT FOR UNIVERSITY JUNIORS, UNIVERSITY FRESHMEN AND HIGH SCHOOL STUDENTS |
|-------------------------------------------------|-----------------|-----------------|-----------------|
| Group                                           | University Juniors | University Freshmen | High School Students |
| Timing of tool use                              | Start of second term | End of first term | Start of second term |
| Number of participants                          | 90               | 92               | 26               |
| Prerequisite knowledge                          | With             | Without          | Without          |
| Lecture time                                    | 45 min           | 30 min           | 20 min           |
| Tool                                           | Unused           | One tool per group of 4 | One tool per person |
| % that understood bit synchronization           | 80%             | 67%             | 84%             |

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The questionnaire result from high school students with correct answers is shown in Fig. 8 (b). There were no students who were able to understand the concepts without using our tool. When P1 was answered incorrectly, all the later problems were answered incorrectly. Students with incorrect answers to P1 used our tool in groups of 2 people. The number of students who could understand the concepts by using our tool was more than 70% for all the problems.

The result was better for high school students (one learning tool per person) than university students (one learning tool per group of 4), so we thought that students should use our tool by themselves. Even without prerequisite knowledge, students can understand the basic concepts of bit synchronization by using our tool in almost the same amount of time as a lecture in the junior year of university. This suggests that our tool can facilitate understanding when learning bit synchronization. We think that our learning tool is valid.

Fig. 7. Percentage of correct answers.

Fig. 8. Questionnaire results from students with correct answers.

VII. CONCLUSION

In this paper, we proposed and implemented a learning tool for bit synchronization in asynchronous communication. This tool is intended for the data link layer, which has not been examined in previous research. Learners learn heuristically by themselves using trial and error. To evaluate the effectiveness of our tool, we did experimental lessons on network protocols for 26 high school students. After this lesson, we had our participants solve 3 problems and had them answer 2 questionnaires. We found that the percentage of correct answers in all of the problems was more than 80%. The results from the questionnaires showed that the number of students who could understand the problems by using our tool was more than 70% for all problems. Based on these facts, we were able to confirm the effectiveness of our tool for network protocol education.

As our next step, we try to extend our tool to character synchronization. Then, we also try to improve the GUI interface. Moreover, we also try to examine the effectiveness
of our learning tool by increasing the number of research participants.

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